QUANTUM GENERATION™: QSAT™ BLOCKCHAIN CONSTELLATION DESIGN
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QUANTUM GENERATION™ (QG™) SPACE TECHNOLOGIES

Abstract. QSAT™ is a unique blockchain constellation design in which each satellite delivers 180 Gbps capacity to end-users. QG is eight times more than the closest upcoming competition. QSAT™ Blockchain satellites use our patent-pending Quantum Generation spot-beam technology and patented QUBIT Blockchain®. However, such high data rates require relatively large electric power and associated supporting elements, but all within a small satellite form factor and mass. In this yellow paper, we establish the feasibility of achieving this goal and present critical parameters of the design.

Contents

1. Introduction

Geo and Meo's satellites have provided connectivity to regions that are beyond the reach of terrestrial infrastructure. Today, substantial tone-class satellites in the geostationary orbit provide basic connectivity. However, due to high costs, these services are primarily restricted to niche sectors like the military and government.

LEO satellites is transforming the entire satellite industry that is going through a wave of technological disruption with the entry of dynamic and agile startups. These players promise to provide internet connectivity using hundreds of satellites in Low and Medium Earth orbits (LEO and MEO). these satellites are by design significantly closer to Earth, they achieve fiber-like latencies unlike their geostationary counterparts.

Recognizing there have been attempts in the past, though unsuccessful, to provide internet from satellites in LEO and MEO. Their failure mainly attributed to costs and commercial reasons. [24].

Due to the growth and trend in the satellite industry and quantum communications, it has provided a conducive environment for successfully delivering the new infrastructure from space. Over the years, satellite launch costs have dropped while the capacity achieved by a single satellite has increased [12], [2]. With new innovation and the deployment of new satellite internet visionary's, and companies are in a unique position to leverage these developments and reduce the cost of developing space infrastructure.

While these factors do reduce the cost of the internet delivered from space, more needs to be done to commodify satellite internet truly.

Specifically, satellites need to have an order of magnitude higher capacity than the current state-of-the-art. Enable satellite internet to transform markets and making the internet accessible to every corner of the world to consumers. Quantum Generation™' goal is to commodify satellite-based infrastructure and communications ecosystem services by building a constellation of ultra-High Throughput Satellites (ultra-HTS) in LEO.

The paper provides the technical feasibility of QSAT™. Matters related to business and financial viability of the project explained in detail in Quantum Generation™' White Paper[17].

1.1 **Introducing QSAT™.** QSAT™ is a unique constellation design of ultra-HTS with a quantum mesh network in LEO and QKD. These satellites will operate in Quantum millimeter-wave frequencies and together provide close to 24 Tbps network capacity. QG achieves a throughput of about 180 Gbps user capacity per satellite. QG higher magnitude than can perform better than other satellites' upcoming constellations. Moreover, the QSAT™ constellation is designed exclusively to serve the developing world, which is the region of the next billion internet users.

2. QSAT™ Blockchain Constellation. QSAT™ will be a constellation of 2000 satellites, with the initial arranged in 11 orbital planes, and inclined at 30◦ concerning the equatorial plane. There are several other upcoming satellite constellations for internet services. However, ours built on the quantum mesh network, and we are creation QG. All of them have a significantly more significant number of satellites than QSAT™. Table 1 compares QSAT™ to other major upcoming constellations.

3. With the QG capacity we deliver per satellite near eight times higher as compared to other constellations. As a result, QSAT™ achieves a network capacity of 24 Tbps. QG Delivers with its patent- pending, Quantum Generation spot-beam technology that has been developed by Quantum Generation™. This global transformational technology can be reviewed in greater detail in Section 4.

a. **Communication Payload.** Each QSAT™ satellite will carry a communication payload developed using Quantum Generation™' spot-beam technology. The communication payload design can form three different types of links, making QSAT™ a fully integrated network of satellites.

The different links formed by the QSAT™ satellites reviewed below.

b. **Quantum Mesh Network Gateway Links:** QSAT™ connects to the terrestrial infrastructure through internet gateways. While each satellite can form a large number of beams, up to four of them are dedicated to establishing connections with the internet gateways. Each of these links is designed to have a capacity of 25 Gbps, and they ensure high-speed data transfer between QSAT™ satellites and the terrestrial internet.

(1) **User Links:** Quantum Generation™' spot-beam technology enables each satellite to form up to a thousand beams. These beams have a cumulative symmetric capacity of 180 Gbps (uplink + downlink), ensuring a high bandwidth internet connectivity to both home and business users.

(2) **Inter Laser -Satellite Links:** In addition to communicating with receivers on the ground, QSAT™ Blockchain satellites are designed to communicate with their neighboring satellites. QSAT™ satellites designed with up to six links dedicated to inter-satellite communication. Each of these links can support data rates of up to 20 Gbps. This feature enables QSAT™ Blockchain constellation to provide connectivity to users, both on land and at sea. Providing QSAT™ the capability to be a Tier-1, Tier-2, and Tier-3 network simultaneously [25, 26].

Design and description in greater detail in Section 4.

The average power consumption of the payload to provide the stated capacity is of the order of a kilowatt. Presenting a significant challenge for a small satellite. The design of the electric system of QSAT™ reviewed in Section 3.1. This high load also translates into a thermal system challenge which would nearly reject the same amount of power as heat to maintain the satellite temperature

Constellation	No. of Satellites	Capacity/satellite (Gbps)	Network Capacity (Tbps)
OneWeb	720	8.8	1.6
SpaceX	4425	20.0	23.7
TeleSat	292	36.0	8.0
QSAT™	200	180.0	24.0

Table 1. Upcoming constellations [14, 15]

within desired range. The thermal system design reviwed in Section 3.2.

Attitude and Orbital Control System (AOCS) maintains stable satellite orientation, required for the wireless links to operate reliably. The design of this system shown in Section 3.4.

a. **QSAT™ Ground Network.** QSAT™ integrates seamlessly with the orbital quantum mesh network infrastructure through the node to node device to device internet gateways scattered all across the service region. The number of required internet gateways is about 250. Each gateway can simultaneously connect with up to four satellites, each with 50 Gbps symmetric capacity. Thus, each portal designed for 200 Gbps symmetric capacity. Depending on the requirement, data would generate routing to Tier-1, Tier-2, or Tier-3 networks, thus extending the reach of terrestrial internet to previously inaccessible geographic regions.

b. **User Equipment.** For an individual user, accessing the internet service provided by QSAT™ Blockchain constellation would be as simple as accessing QGSAT programing for residential satellite TV & fast Internet. QG products include QWifi, QPhone, and Qantenna connected to a companion router inside the premises. The Qrouter, in turn, would provide the orbital and ground Quantum Mesh network and incentivized P2P, quantum mesh network. Additionally, QGSAT Satellite user we will provide bandwidth to telecom operators. QSAT enables them to extend their 4G/5G services to regions without having to rely on fiber and will integrate QG as a standalone Band. Technical details of user devices reviewed in Section 4.

Summary

- QSAT™ t constellation design consists of 200 satellites in 11 orbital planes at 30° inclination.
- QSAT™ satellitecommunicationpayload uses Quantum Generation™ spot-beam technology to achieve a total network capacity
- Each QSAT™ satellite provides nearly 8× more capacity than that of any other upcoming constellation.
- QSAT™ provides Tier-1,Tier-2andTier-3 network servicessimultaneously.

c. **C. QSAT™ Blockchain Constellation** The QSAT™ Blockchain constellation with QUBIT Blockchain has been specifically designed to meet its business goal of providing broadband internet connectivity to developing countries. Since almost all developing countries located between 38◦ North and 38◦ South latitudes, the constellation is designed to cover only this region (area of interest). Thus, QSAT™ 's entire network capacity concentrated on areas that are experiencing tremendous growth in internet penetration. The coverage region of the satellite shown in Figure 1, while Appendix B provides list of the countries that can be served by QSAT™ .

2.1 Constellation Design. Orbital simulations demonstrate that a Walker-Delta [11] constellation with 200 satellites, each with a payload field of view 37◦, is sufficient to achieve complete coverage of the area of interest. The orbital parameters of QSAT™ satellites summarized in Table 2. The constellation requires minimal station keeping because of every satellite constellation has the same altitude and inclination.

Parameter	Value
Altitude	1530km
Inclination	30°
No. of planes	11
No. of satellites per plane	18

Table 2. Orbital parameters of QSAT™ satellites

Simulations of the constellation show that, on average, user links need to operate for approximately 64% of the time. Reducing the average demand on the power subsystem, reducing its size and weight. Further optimization achieved by running the user payload at 25% of its full capacity when the satellite is over uninhabited regions, including seas and oceans. The quality of service is not affected as the demand from these regions is also significantly low. With this, the constellation simulations yielded a duty cycle.

	Duty Cycles	
	Average %	Worst %
Payload		
User	25	34
Internet Gateway	27	43
Inter-satellite	75	100
System bus		
Housekeeping	100	100

Table 3. QSAT™ subsystem duty cycles

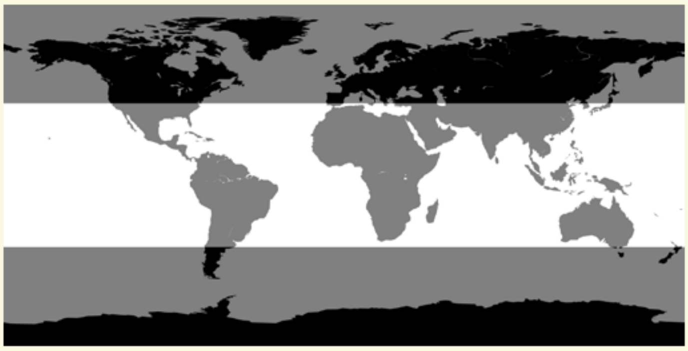


Figure 1. Coverage region of the QSAT constellation

2.1. **Deployment Phases.** The constellation will launch in three phases, QSAT™ –QG25 with 25 satellites, QSAT™ –100 consisting of 100 satellites and QSAT™ –200, consisting of the full constellation of 200 satellites. And over five years of 2000 satellites. Each phase progressively increases the constellation's capability to serve more classes of applications. **QSAT™ –25**. This first phase consists of a pilot constellation with 25 satellites distributed equally.

of 34% for the user payload and 43% for gateway payload. Summarized in Table 3. across all 11 planes. This phase provides high bandwidth connectivity for delay-tolerant applications. The satellite revisits a time in which this phase is around 45 min for any service area. In this phase, the satellite can launch through 11 dedicated launches on one or several small satellite launchers. Please note that satellites will inject at the final orbit locations that they would assume in QSAT™ –200 constellation. Figure 2 shows a simulation snapshot of the QG25 satellites of this phase against a background of the world.

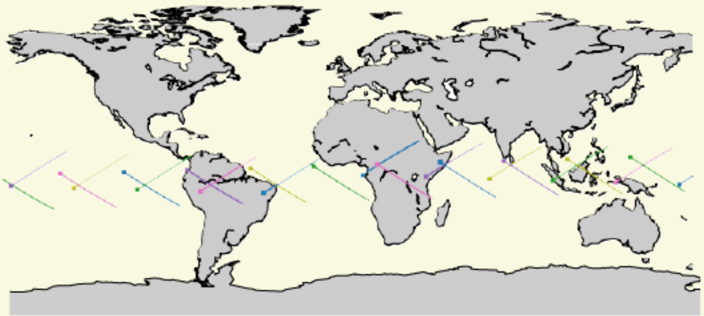


Figure 2. Illustration of QSAT™ –25

QSAT™ –QG100. In this phase, the pilot constellation expanded to an intermediate constellation. We accomplish this by populating all the 11 planes with half the number of satellites (9 per plane). The objective would be to provide partial coverage of the area of interest, with a focus on full coverage of specific developing countries. This phase would require 11 dedicated launches using launchers capable of carrying 10 QSAT™ satellites each. These, too, are injected at the final orbit locations that they would assume in QSAT™ –QG200 constellation. Figure 3 shows a simulation snapshot of the QG 00 satellites of this phase against a background of the world. Inter-satellite communication is disabled in this phase, due to large in-plane and cross-plane satellite distances.

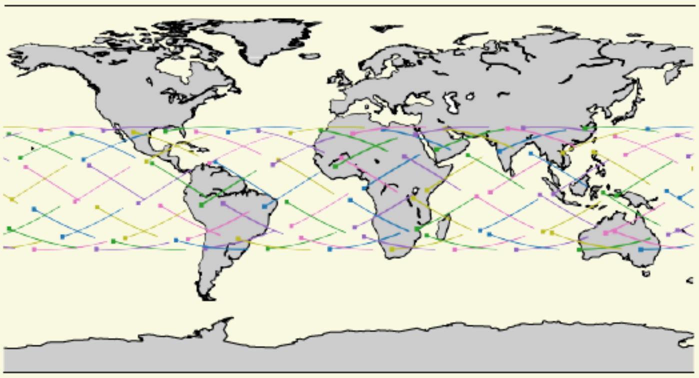


Figure 3. Illustration of QSAT™ –99

QSAT™ –QG200. During the phase, it involves building the full constellation through the launch of 100 satellites in their designated orbit. Figure 3 demonstrates a simulation snapshot of all the QG200 satellites orbit around the globe. The execution of this phase provides continuous network coverage over the entire area of interest. Additionally, in this phase, inter-satellite communication payload is switched on, which establishes the Tier-1 network in space.

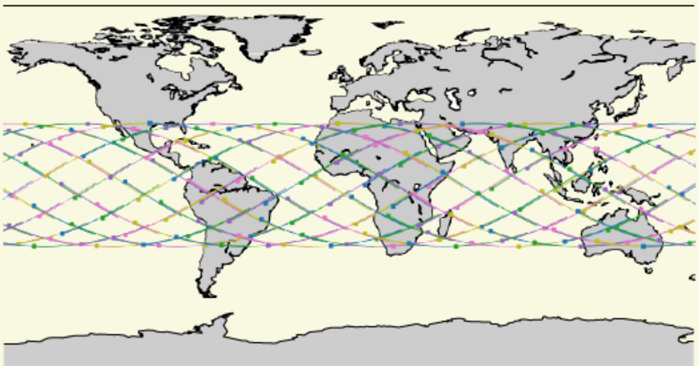


Figure 4. Illustration of QSAT™ –QG200

2.2. **Launch Requirements.** Essential requirements for the launch of each of the above phases are:

(1) A launch vehicle is chosen such that it can inject the satellites into the mission orbit directly. Otherwise, the satellites will have to carry additional fuel to power the necessary orbit maneuvers.

(2) A dedicated upper stage dispenser will be required if a single launcher is carrying multiple QSAT™ satellites.

(3) Enable a direct injection into a 30◦ inclined orbit; the launch site latitude should be 30◦ or less.

2.3. Constellation Management.

Active constellation management is required to have a high service level availability. All QSAT™ satellites have a design lifetime of 5-7 years, after which they should replace new satellites. However, if a satellite malfunctions, it would require an early replacement.

LEO satellites typically exhibit reliability in the range of 60–85% at the end of 5 -7 years. Translating to 30–80 failures in a span of five years, i.e., 1–2 months of the mean time between failures (MTBF) for a constellation of 200 satellites.

Replacement of failed satellites is planned to be accomplished using a combination of the following strategies. [3]:

(1) **Redundant design:** The QSAT™ design is inherently tolerant to the failure of one satellite. Upon failure of anyone satellite, an on-ground spare launched before the next collapse. This scheme ensures that the required service availability is maintained.

(2) **Spares near the same orbit:** In this case, the replacement satellite launched into an orbit of slightly lower altitude with matching orbit precession. Upon the failure of a single satellite, the corresponding spare maneuvered to the mission orbit position. The required maneuver can be completed in 1–2 days. Thus, this strategy requires 11 spare satellites, one for each plane. Besides, this requires an on-board propulsion system.

(3) **Spares in a parking orbit:** In this case, the replacement satellite launched in a parking orbit at a much lower altitude. Such a satellite could act as a replacement for the entire constellation. It uses the differential precession between the parking and target orbit to allow the spare satellite to attain the plane of the failed satellite. When achieving the required plane, the satellite raised to the target altitude. As compared to spares near the same orbit, this requires a more extensive on-board propulsion system.

2.4. **Deorbiting.** As a responsible satellite operator, we have incorporated a deorbiting mechanism in our design for satellites. We have estimated that electric thrusters of 10 mN can bring down our satellites to a 200 km orbit in about three years. Beyond this, atmospheric drag completes the deorbiting

Summary

- A constellation of 200 satellites distributed in 11 planes at 30° inclination, 1530 km altitude covers the area of interest (region between 38° North and 38° South latitude).
- The constellation will be deployed in three phases of QSAT™ –25, QSAT™ –100 and QSAT™ –200 satellite. Each phase progressively targets greater market segments.
- The constellation design incorporates a replacement plan and a deorbiting plan.

3. Satellite Design

The QSAT™ Blockchain satellite bus consists majorly of the following systems:

- **Power System** to generate and distribute stable power for payload and bus operations,
- **Thermal System** to manage heat generated by payload and bus operations, and,
- **Attitude Determination and Control System allows us** to maintain the orientation of the satellite along the desired direction. The following sections give an overview of the design of each of the above systems.

3.1. Power System.

3.1.1. **Drivers and Rationale**. The essential mission requirements for power system are to generate and store sufficient power, even at the end of life, to provide the necessary power for all payloads at their stipulated duty cycles and to cater for housekeeping power demands at all times during satellite life. Factors that have driven this design are,

(1) Power requirements of different payloads and their respective duty cycles.

(2) Solar illumination and eclipse duration in an orbit.

(3) Constraints imposed by satellite size and complexity of solar array deployment.

By selecting an appropriate solar array pointing scheme, the design maximized the power generation. Besides, the mass and size of both solar array and battery were minimized by accurately estimating the duty profiles of the payload using simulations of the constellation. The degradation of solar cells due to exposure to radiation, as well as capacity degradation of battery cells at the end of life, have been considered in the design of the power system.

3.1.2. **Requirements**. Simulations of our constellation show that a QSAT™ Blockchain satellite will require about 4 kW of peak power and about 1 kW on an average. The breakup of power demands of various payloads and their respective duty cycles is given in Table 4.

3.1.3. Duty cycles for both user and internet gateway link obtained from simulations. These numbers assume that the housekeeping power requirement stays constant at the peak, whereas those for user links, internet gateway links, and inter-satellite links vary with time.

Loads	Average Duty Cycle (%)	Peak (W)	Average (W)
Payload Link			
User	25	2300	575
Internet gateway	27	1200	324
Intersatellite	75	324	243
System Bus	100	100	100
Housekeeping			
Total		3800	1199

Table 4. QSAT™ Blockchain satellite power budget

3.1.4. **Solar Array Panel Design**. Parameters influencing the design are listed in Table 5.

The solar cell efficiency quoted in Table 5 is the end of the life value. The maximum orbit temperature attained by the solar panel was assumed to be 100◦C. Typical packing efficiency of commercially available solar panel solutions used for the design [1].

Parameter	Value
Incident solar radiation	1367.0 W/m^2
Solar cell EOL efficiency	26.5 %
MPPT efficiency	90.0 %
Temperature efficiency	80.0 %
Packing efficiency	76.0 %
Power per unit mass	80.0 W/kg

Table 5. Solar panel design inputs

Parameter	Value
Required area Design area	12.0 m^2
Number of panels per wing	3
Number of deployable wings	4
Solar panel mass (Incl. structural)	30.0 kg

Table 6. Solar array panel design

Stowed solar panels, if overhanging beyond the satellite body, cause vibrational problems. Because of this, it was decided to restrict the size of the panel within the satellite dimensions. Besides, a good design should also minimize the complexity involved in the deployment of the solar panels.

The solar panels are sized to provide the average power required by the satellite, while the battery is sized to cater to the temporal variation of the power requirements. QG maximizes the potential generated; each solar panel tracks the sun by rotating about the longitudinal axis. Besides, the design employs maximum power point tracking (MPPT) for energy transfer between solar arrays and the power bus. Constellation simulations provided the duty cycles of the user and internet gateway payload links over this period. With these design considerations, the total required solar panel area was estimated to be about 12 m^2.

For the ease of deployment and to address concerns related to vibrations in the stowed condition during launch, the solar panels are distributed equally across four wings. Each solar panel was designed to be 1.1 m 1.1 m in dimension. A *wing* consists of three such panels. Four such wings of solar panels mounted on the satellite, gives us a total solar panel a of 14.5 m2, giving us a margin of more than 20% over the required area.

The mass of array panels was estimated from W/kg figures of state-of-the-practice solar array solutions [9]. The total mass of the solar panels including their structural supports was estimated to be about 30 kg. The design is summarized in Table 6.

3.1.5. **Battery Design**. The battery caters to the power requirement during eclipse, as well as peaks in

The power required by the user and internet gateway payload links. The design was for the worst-case scenario, when both the above conditions occur simultaneously, and that too when the eclipse duration is maximum for the orbit. That is, the battery design caters to full load power of both, the user and internet gateway payloads, for a duration of 35 min in eclipse. Additionally, the design assumes that

(1) the battery has already undergone degradation due to 5 years of operations (which evaluates to 23000 cycles),

(2) the depth–of–discharge (DoD) should not exceed 50%.

(3) the battery has at least 65% of the nameplate capacity at the end of life. The key design considerations are presented in Table 7.

Design Parameter	Value
Worst case eclipse	35 min
Worst case energy loss (Start of eclipse)	863 Wh
Worst case energy loss (End of eclipse)	3142 Wh
Allowed DoD	50 %
Number of Cycles	23000

Table 7. Battery design inputs

The size and mass of the batteries are estimated based on gravimetric densities of standard space-qualified Li-ion batteries available commercially. Table 8 presents the battery design in a nutshell. The availability of space-grade batteries with these requirements verified.

Battery Baseline	Value
Required battery capacity	6283 Wh
Battery nameplate capacity	6400 Wh
Battery mass	40 kg
Capacity degradation @ EOL	20 %

Table 8. Battery design inputs

3.2. **Thermal Management System.** The QSAT™ satellite high power to volume ratio limits the maximum allowed area for the radiators. An option exists to increase the energy radiated per unit area by raising the temperature of the radiator surface using heat-pumps.

However, our design did not use this option because heat pumps come with a prohibitively high mass and power penalty for a small satellite. The user and the internet gateway payload operate intermittently, phase–change materials (PCM) can use for temporarily storing the heat to be radiated later by the radiators. The latent fusion heat of such materials enables heat absorption with no rise in temperature.

The objective of the thermal system design is to maintain operable temperatures for the components of the satellite. The design involves estimating necessary radiator area and the PCM mass. Typical values have been assumed for the properties of radiator and the PCM. This is listed in Table 9. End-of-life (EOL) values have been considered for the surface characteristics of the radiator.

The radiator surface temperature is assumed to be 40 °C. Assuming the maximum allowed payload temperature is 80 °C, this ensures about 40 °C as the available temperature gradient. The design assumes a conservative radiation sink temperature of −173 °C (100 K).

Parameter	Value
Absorptivity	0.21
Emissivity	0.77
Radiator temperature	40.0 °C
Sink temperature	100.0 K
Radiator specific weight [10]	8.0 kg m^{-2}
PCM latent heat [16]	180.0 kJ kg^{-1}

Table 9. Thermal design inputs

The required radiator area is primarily driven by the average heat generated, while the PCM mass is driven by the ON-time duration of the payloads.

As discussed in previous Section 2.1, the satellite payload duty-cycle changes continuously. It is, there- fore, prudent to use the maximum ON-time duration the satellite is required to perform as the worst case for thermal calculations. This is summarized in Table 10.

Heat Source	Peak Duty Cycle (%)	Peak (W)	Average (W)
Payload Link			
User	34	2300	782
Inter-satellite	100	324	324
Internet gateway	43	1200	516
System Bus			
Housekeeping	100	100	100

Table 10. Heat-load distribution

The average heat generated is dominated by the constant housekeeping power and inter-satellite pay- load power. Thermal solar load incident on the radiators can be very detrimental to their efficiency. The design orientation of the radiator minimizes the solar load. Thermal cooling for QSAT™ satellites is possible through a passive scheme. Temperature control is actively accomplished with sub-system heaters.

The payload heat is transferred directly to the radiators using heat-pipe embedded conductive plates (heat spreaders) and also through the bus panels. The heat-pipes ensure that the heat is transferred with minimal drop in the temperature. Heat pipes embedded in the radiators ensure close-to-uniform temperature distribution, thus increasing their efficiency.

Sufficient margins have been provided in the PCM mass estimation to cater to delays in the phase change process. Multi-layer insulation (MLI) is used on the bus panels wherever necessary along with thermal isolators and thermal pads to ensure optimum sub-system temperature control with minimal use of heaters.

The total required radiator area was thus estimated to be 6 m^2. The radiators can radiate heat from both sides, hence, three deployable radiators of size 1.1 m 1.1 m provide 7.2 m^2 of radiating area, thus giving us a margin of 22%.

The radiators are attached to the side edges of the satellite bus using high thermal-conductivity hinges. Side bus panels receive minimum solar incidence making them suitable for radiator mounting (See Figure 5).

PCM mass required is a strong function of the number of ON/OFF duty cycles that will performed in an orbit. Table 11 summaries the variation of required PCM mass with the number of ON/OFF duty cycles in an orbit.

Duty Cycles	Cycle Time (min)	ON Time (min)	PCM Mass (kg)
1	117	70	38
2	59	35	26
4	29	18	20
8	15	9	17

Table 11. PCM mass for varying duty-cycles

Notice in Table 11 that the PCM mass required drops rapidly as the number of duty cycles per orbit is increased. The above data is generated by varying the number of ON/OFF cycles per orbit for user-link and internet-gateway link while maintaining their duty cycles shown in Table 10.

The design assumed a worst case of single duty- cycle for both, the user-link as well as the internet- gateway link. This gives a total PCM mass of 38 kg including a 25% margin. The overall system level thermal specifications for the QSAT™ satellites are summarized in Table 12.

Parameter	Value
Number of panels	3
Radiator panel size	1.1 1.1 m^2
Total radiator mass	29 kg
PCM mass	38 kg

Table 12. Thermal design specifications

3.3. **Structural Configuration.** The QSAT™ satellite bus is a cube of side 1.1 m, which comes under the small satellite class.

The structure comprises of 4 wings having triple deployable sun tracking solar array panels on each wing. They are mounted on four opposite edges of the bus with its own rotating drive mechanism. Each solar array panel is with a side of 1.1 m. This results in a total area of 3.63 m^2 per wing. These panels will be stacked along the opposite edges of the satellite during launch and will be deployed in a single plane later.

The satellite also comprises of three deployable thermal radiators mounted along the edges normal to solar array panel using hinged supports. Each radiator panel is 1.1 m 1.1 m, so that it can be stacked beneath the solar array panels while launching and will be deployed along the plane, normal to the solar array panels. Figure 5 gives an artist's impression of QSAT™ Blockchain satellite in a fully deployed configuration.

Figure 5. Artist's impression of QSAT™ satellite

QSAT™ satellites carry eight payload units. Six of these units mounted on the side panels of the satellite form high-speed links with four neighboring satellites. The remaining two units, which communicate with the user and internet gateway, will be mounted on the earth pointing face of the satellite bus. All other subsystems of the satellite can easily accommodate within the inner walls of the satellite bus.

Al-6061, an aluminum alloy with good strength– to–weight ratio, is suitable for manufacturing the satellite structure. Furthermore, honeycomb type bus panels offer a better strength–to–weight ratio as compared to truss type and skin-frame type panels. These honeycomb structures are readily available in the market with different cell sizes and thicknesses.

The mass budget of the QSAT™ Blockchain satellite structure is shown in Table 13, while that of the entire satellite with all the subsystems is shown in Table 14.

Parameter	Value
Honeycomb cell size	6 mm
Honeycomb thickness	25 mm
Honeycomb density	80 kg m^{-3}
Al6061 sheet thickness	0.5 mm
Structural margin	30 %
Total structural mass	44.4 kg

Table 13. Structural mass budget [4]

Parameter	Value
Power subsystem	110.0 kg
Thermal system mass	67.4 kg
Payload	32.2 kg
Structural	44.4 kg
Radiation shielding	15.6 kg
AOCS	6.1 kg
Sub-total	276.0 kg
Telemetry	3.0 kg
Harnesses/Cables	5.5 kg
Deorbiting propellant	9.8 kg
AOCS propellant mass	0.5 kg
Total	295.0 kg

Table 14. Mass budget of QSAT™

3.4. **Orbital Characteristics.** The satellite's orbit gets affected by atmospheric drag and solar radiation. QSAT™ has an altitude of 1530km, at which atmospheric disturbances are negligible. Hence, orbit degradation is negligible for 5 to 7 years of satellite life.

3.5. **Radiation Environment.** The satellites in the selected orbital configuration are prone mostly to low-energy electrons and high-energy protons. Either of them can cause temporary or permanent damage to the satellite electronics. Design of the circuits takes enough care to prevent any discontinuity in operation even after certain single event effects. Moreover, electronics are shielded to reduce the damage caused due to the total ionization dose (TID) over the lifetime of the satellite. The radiation tolerance levels of some components used in satellites are given in Table 15.

Component	Tolerance (krad)
Full-differential Amplifier	150
Analog to Digital Converter	150
Digital to Analog Converter	100
Space-grade clock	100
Differential Receiver	100
Digital Signal Processor	150

Table 15. Radiation tolerance [6]

As shown in Table 15, the satellite electronics should have sufficient shielding to limit TID to a maximum of 20krad per year for the satellite's life- time. Simulations confirmed that a total shielding of 8 mm of aluminum for electronics can limit the TID to within the said level, while adding only 15.6 kg to satellite mass. The selected configuration provides a margin of at least 10% over the lifetime of the satellite.

3.6. **Attitude and Orbit Control System.** After insertion into the orbit, QSAT™ satellite needs to detumble. This which can be achieved using reaction control thrusters. The satellite needs to maintain its nominal Earth pointing attitude throughout the orbit. Reaction wheels can be used for attitude control, while sun-sensors, star-trackers and gyroscopes can be used for attitude estimation. Reaction control thrusters can be used to compensate the effect of disturbance torques. As the satellite assumes a nominally Earth-pointing mode during its operations, the control system requirements pose no significant challenge to feasibility. Partial constellation of QG100 satellites 2.2, covers particular region on Earth by tilting the satellites. Reaction wheel requirement for partial constellation specifically for tilting the satellites is around 0.1 N m of torque and 0.5 N m s of momentum. Reaction wheels of mentioned requirements is available in the market.

Summary

- The satellite bus is a cube of side 1.1 m.
- The peak and average power requirement of the satellite is 4 kW and 1.2kW respectively.

- A 15 m^2 solar panel area provides sufficient power to the satellite bus and payload at its end of life.
- A 6400 Wh battery provides sufficient storage to cover the operations during eclipse and the peak load orbits.
- Three square radiators of side 1.1 m each and 38 kg of PCM caters to the rejection of heat generated by the satellite bus and payload.
- The total mass of the satellite is about 300 kg.
- The selected orbit has negligible orbit degradation over 5 years.
- 8 mm of aluminum provides sufficient radiation shielding over the lifetime of the satellite.

d. Payload Technology

The wireless communication payload of QSAT™ satellites, uses a unique patent-pending spot-beam technology which allows forming multiple beams simultaneously with one transponder. This spot-beam technology allows for packing several hundred up to thousand spot-beams in one transponder. Multiple spot-beams [23] can be created in several ways-

(1) **Single-feed antenna:** In a single-feed antenna design, typically, a high gain horn antenna is used usually along with a reflector to provide a spot-beam which is with a fixed orientation and is not steerable [18, Section 3]. This would mean that for creating 'N' spot beams, you need 'N' antenna and corresponding reflector making it suitable only for small number of spot beams. In effect, this is a system where 'N' non-steerable spot beams are created with an array of 'N' antenna elements.

(2) **Sub-array feed array antenna:** In cases where more power is desired, multiple elements would be needed for each spot beam to work. This is a concept which is realized with array of antenna elements where sub-groups of it contribute to each spot beam to realize multiple spot beams. See [18, Section 4] for example. In this case as well, the number of spot beams are fixed as well the spot beams are non-steerable. OneWeb's satellites are expected to have similar design [13].

(3) **Phased array antenna:** In both of the above cases, spot beams are inherently not steerable. If steerability is additionally desired, then mechanical rotation systems will have to be added making it bulky. Phased array of antenna is a solution to steerability. Here, one signal is fed to different antenna elements with different phases using controlled phase shifters to provide constructive signal interference along a direction of interest. See [22] for more explanation. This is quite commonly employed by all upcoming generation of satellites. See for instance, Viasat [5] and Starlink [19]. However, this is still about one spot beam. So, an entire array of antenna elements with phase shifters can form one beam. To create 'N' beams, one would need 'N' such phase array antenna, making it not scalable.

Our spot-beam technology is different from all the above as explained below.

(1) **No sub-array:** Each antenna element in our ar- ray contributes to every spot beam. This means that it is not a sub-array or single feed per beam. Rather, all elements participate for each spot beam.

(2) **Multi-digital beam-forming:** We have an new architecture design which allows for multiple spot beams to be realized, all in digital, allowing a single antenna array to form multiple steerable spot beams. Also, we can define the width of each beam electronically making it truly flexible and adaptable to different service requirements.

(3) **Active Power Modulation:** Our array design supports active power modulation per beam thus adapting to link requirements based on cloud and rain conditions.

We have validated our spot-beam technology in lab environment and in the process of doing a range test of a few kilo-meters in coming months. We will discuss in the following sections, how our spot-beam technology will be used to realize the necessary communication links.

The spot-beam technology described above is a physical layer innovation. Apart from that, in QSAT™ satellites, there will be building handling of MAC and IP layers of internet protocol stack [21], making each of our satellites as Layer-3 routers. Each QSAT™ satellite will have three types of links as shown in Figure 6. They are detailed below.

4.1. **Satellite to User Links.** Each QSAT™ satellite by design will consist of a dedicated user communication payload, which forms a direct link with user devices. The user communication payload creates several hundred, up to thousand spot beams, each of less than 2 degrees. Each spot beam can provide a data rate of up to 500 Mbps symmetric (uplink + downlink) with a channel bandwidth of 120 MHz. Using a frequency reuse pattern, we can effectively provide about 180 Gbps symmetric across the entire service area using less than 500 MHz of bandwidth. Important details of this link reviewed in Table 16.

Parameter	Value
Uplink Frequency Range	81 GHz to 86 GHz
Downlink Frequency Range	71 GHz to 76 GHz
Beam Bandwidth	120 MHz
Beam angular width	<2 degrees
Path loss	196 dB
Atmospheric loss	1 dB
Rain and cloud loss (99.5% case)	40 dB
Symmetric data rate per beam	500 Mbps
Aggregate throughput	180 Gbps
SLA (%)	99.5%
Maximum users per satellite	100,000
Half-cone angle from satellite	±35 degrees
User terminal size	≈1 foot^2
Minimum elevation at user terminal - 45 degrees	

Table 16. Important parameters of user link

Service Level Availability (SLA). An important measure of any link is its service level availability. We provide Figure 7 indicating the availability of said capacity to end-users as a function of percentage of time in a year. We expect that an SLA of 99.5% is achievable with a minimum speed of about 2 Mbps for a user, while for major part of the time in the year, the user will have maximum speed as perhis/her subscription. We have followed ITU's rain and cloud models to compute these SLAs [7, 8].

4.2. **Satellite to Internet Gateway Links.** QSAT™ satellites need to be linked to terrestrial internet at suitable places so that data hand-over of QSAT™ users can occur with terrestrial internet, which is typically internet exchange points [20]. We call our terminals, which link to internet exchange points as internet gateways. Each QSAT™ satellite is designed to connect with up to 4 gateways. Each link to sent to the internet gateway designed so it can provide up to 50 Gbps symmetric data rate with an aggregate capacity of 200 Gbps across four links. The essential parameters of this link summarized in Table 18 and throughput to SLA variation given in Figure 9. We expect to deploy about 250 internet gateways globally to provide adequate connection to terrestrial internet as indicated in Table 17 and Figure 8.

Continent	Percent
Asia	30.77 %
Africa	25.00 %
South and Central America	23.08 %
North America	11.54 %
Oceania	7.69 %
Europe	1.92 %

Table 17. Continent-wise distribution of internet gateways.

Parameter	Value
Uplink Frequency Range	81 GHz to 86 GHz
Downlink Frequency Range	71 GHz to 76 GHz
Beam Bandwidth	4.5 GHz
Beam angular width	<3 degrees
Path loss	195 dB
Atmospheric loss	1 dB
Rain and cloud loss (99.5% case)	40 dB
Symmetric data rate per link	50 Gbps
Aggregate throughput	200 Gbps
Maximum number of links	4 (on both sides)
SLA (%)	99.5%
Ground terminal size	≈9 foot^2

Table 18. Important parameters of internet gateway link

Figure 6. Different Links from QSAT™ satellite

4.3. Satellite to Satellite (Inter Laser satellite) laser Links. One of the critical uniqueness in our constellation is the presence of very high throughput inter-satellite links, which enable a Tier-1 network in space. Each QSAT™ blockchain satellite is being designed to have up to 6 inter-satellite links capable of communication up to a distance of 3000 km. The six inter-satellite links that will be supported are as follows:

(1) **Inter Laser links.** Two inter-satellite links are always established with previous and next satellites within the same plane of orbit.

(2) **Inter Laser links.** Four inter-satellite links are established based on availability with satellites in adjacent planes. From our design simulations, we expect that on an average 75% of the time, at least two of these inter-ring links are available for each QSAT™ satellite. Each inter-satellite link is designed to have about 40 Gbps symmetric capacity. Important parameters of these inter-satellite links are listed in Table 19.

Summary

•QSAT™ is designed with a unique patent-pending Quantum Generation spot-beam technology and Quantum Mesh orbital and ground network which allows multiple spot beams with one transponder.

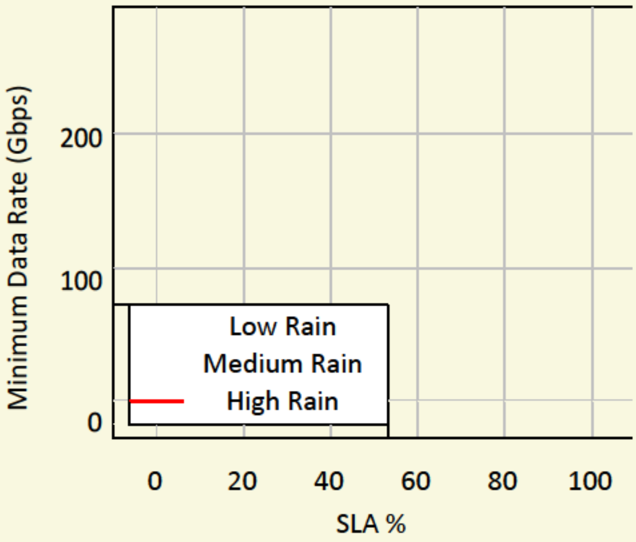


Figure 7. Minimum Aggregate Capacity of User-Link available over a year

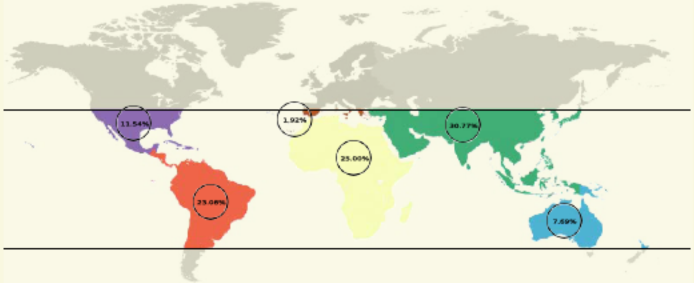
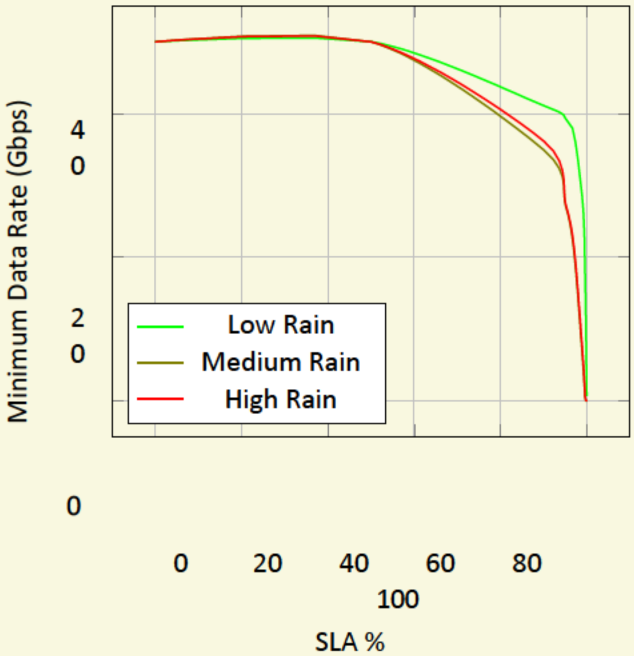


Figure 8. Distribution of internet gateways



- Each QSAT™ satellite provides a global quantum mesh network.

Parameter	Value
Frequency Range	66 GHz to 71 GHz
Beam Bandwidth	5 GHz
Beam angular width	<0.5 degrees
Path loss	195 dB
Symmetric data rate per link 40 Gbps	
Aggregate throughput	200 Gbps
Maximum number of links	6
SLA (%)	100%

Table 19. Important parameters of inter-satellite link

– 180 Gbps for user communication.

– 200 Gbps for linking to internet ex-change points.

– 200 Gbps for inter-satellite links.

- Up to 100,000 users can be served per satellite-
- About 250 internet gateways to be deployed Globally.
- QSAT™ satellites work up to Layer-3 (Quantum Mesh Network Protocol) layer unlike many other constellations.
-
-

Conclusion and Future

In this paper, we have presented the feasibility of QSAT™ blockchain constellation and its capability by design to deliver 180 Gbps throughput per satellite with an aggregate network capacity of 24 Tbps. We have presented the feasibility of the constellation design itself and all major systems of QSAT™ satellite, including power, thermal, AOCS, and radiation. Additionally, we have presented the link budget of various wireless links in each of QSAT™ satellites. This paper also provides a clear distinction in terms of core tech.

Figure 9. Minimum Capacity of one quantum nesh Gateway Link technology and overall capability of QSAT™ satellites compared to state-of-the-art as well as upcoming constellations. With the feasibility of the overall system in-place, we will be next working on detailed system design and implementation to realize the actual hardware. As mentioned before in Section 4, our patent-pending quantum generation beam technology has been validated in lab and

is undergoing range tests currently. We plan to do an in-orbit test via hosted payload opportunities or an independent nano-satellite launch in 2020, to do any finer adjustments for use of the technology in space. Parallelly, the final payload system's detailed design will be undertaken and full implementation will be taken after in-orbit test. QSAT™ constellation will subsequently be deployed as per the plan given in Section 2.2.

Appendix A. Terminology

Quantum Mesh Gateway: QG gateways in the context of QSAT™ blockchain constellation are those which link QSAT™ satellites to internet exchange points [20].

Symmetric Capacity: Symmetric capacity of a link is simply the sum of its uplink and downlink capacities.

Constellation: Constellation is a group a satellite launched in coordinated regular orbits to achieve specific service targets.

Mbps: Megabits per second. It is used in this paper to denote data-rate of user links. To relate this to volume of data, 1 megabyte (MB) of data can be transfer in 8 seconds with 1Mbps link.

Gbps: Giga bits per second. It is used in this pa- per to discuss date-rate of internet gateway and inter-satellite links.

Appendix B. List of Countries Covered by QSAT™ –200

Angola, Bahrain, Barbados, Bahamas, Bangladesh, Belize, Benin, Brunei Darussalam, France, Cambodia, Sri Lanka, Burundi, Bhutan, Cameroon, Comoros, Costa Rica, Central African Republic, Cuba, Cyprus, Djibouti, Dominica, Dominican Republic, United Arab Emirates, Equatorial Guinea, El Salvador, Ethiopia, Gambia, Ghana, Grenada, Guam, Zimbabwe, Timor-Leste, Palau, Greece, Guyana, Haiti, Honduras, Cote d'Ivoire, Jamaica, Democratic People's Republic of Korea, Kiribati, Lebanon, Liberia, Guadeloupe, Western Sahara, Montserrat, Japan, North America, Philippines. Morocco, Algeria, Libyan Arab Jamahiriya, Egypt, Israel, Jordan, Saudi Arabia, Iraq, Kuwait, Islamic Re- public of Iran, Afghanistan, Pakistan, India, Nepal, Mexico, Palestine, Montenegro, Mayotte, Senegal, Singapore, Sierra Leone, Mauritania, Mali, Oman, Malta, Niue, Aruba, Anguilla, Hong Kong, New Caledonia, Gibraltar, Macau, Paraguay, Panama, Burkina Faso, Suriname, Niger, Chad, Sudan, Syrian Arab Republic, Eritrea, Yemen, Burma, Thailand, Vietnam, Philippines, Puerto Rico, Rwanda, Seychelles, Saint Kitts and Nevis, Saint Lucia, Guatemala, Botswana, Nicaragua, Cape Verde, Sao Tome and Principe, Gabon, Congo, Saint Martin, Portugal, Papua New Guinea, Guinea-Bissau, Qatar, Reunion, Democratic Republic of the Congo, Uganda, Kenya, Somalia, Malaysia, Indonesia, Ecuador, Colombia, Namibia, Saint Barthelemy, Angola, Zambia, Mozambique, Malawi, Madagascar, Australia, Vanuatu, Nauru, French Guiana, Peru, Bolivia, South Africa, Trini- dad and Tobago, Lesotho, Chile, Argentina, Lao Peoples Democratic Republic, Tokelau, Togo, Tunisia, Turkey, Tuvalu, Turkmenistan, United Republic of Tanzania, Uruguay, Saint Vincent and the Grenadines, Venezuela, Brazil, Italy, Spain, Taiwan, Fiji.

References

[1] *30% Triple Junction GaAs Solar Cell*. Aug. 2016. url: http://www.azurspace.com/images/products/0003422-02-02_DB_3G30C.pdf.

[2] Arthur D Little. *High Throughput Satellites: Delivering future capacity needs*. Tech. rep. 2015.

[3] Bello-Mora Comara Beech. *Satellite Constellation Mission Analysis and Design*. 2001. url: https://bit.ly/2Fg1FwY.

[4] HonyLite. *Aluminum Honeycomb Panel*. 2018. url: http://www.universalmetaltek.com/wp-content/uploads/2018/04/Aluminum-Honeycomb-Panel.pdf.

[5] ViaSat Inc. "Multi-beam active phased array architecture". June 2012. url: https://patents.google.com/patent/US8160530B2/en (visited on 06/18/2019).

[6] Texas Instruments. *TI Space Products Guide*. url: https://www.ti.com/lit/sg/slyt532g/slyt532g. pdf.

[7] ITU. *P.838: Specific attenuation model for rain for use in prediction methods*. url: https://www.itu. int/rec/R-REC-P.838-3-200503-I/en.

[8] ITU. *P.840: Attenuation due to clouds and fog*. url: https://www.itu.int/rec/R-REC-P.840-7-201712- I/en.

[9] JPL. *Solar Power Technologies for Future Planetary Science Missions*. Dec. 2017. url: https://solarsystem.nasa.gov/system/downloadable_items/715_Solar_Power_Tech_Report_FINAL.PDF.

[10] Albert Juhasz and George P. Peterson. *Review of advanced radiator technologies for spacecraft power systems and space thermal control*. July 1994. url: https://www.researchgate.net/publication/ 24301713 _ Review _ of_ advanced _ radiator_ technologies_ for_ spacecraft_ power _ systems _ and _ space_thermal_control.

[11] Kelvin Loh. *Walker-Delta Satellite Constellation for Earth Observation*. 2012. url: https : / / www . academia.edu/5253116/Walker-Delta_Satellite_Constellation_for_Earth_Observation.

[12] Michael Moe, Luben Pampoulov, Nick Franco, Suzee Han, Emily Ha, Ben Fife, and Jackson Stone. *Sticking the Landing*. 2017. url: http://www.a2apple.com/sticking-the-landing/.

[13] FCC Filing OneWeb. *OneWeb Non-Geostationary Satellite System (LEO), Attachment A, Technical In- formation to Supplement Schedule S*. 2018. url: http://licensing.fcc.gov/myibfs/download.do?attachment_key=1357110.

[14] Inigo del Portillo, Bruce G. Cameron, and Edward F. Crawley. "A Technical Comparison of Three Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband". In: *69th International Astronautical Congress, Bremen, Germany*. 2018.

[15] Larry Press. *Simulation of OneWeb, SpaceX and Telesat's Proposed Global Broadband Constellations*. Jan. 2019. url: http : / / www . circleid . com / posts / 20190102 _ simulation _ of _ oneweb _ spacex _ telesats_broadband_constellations/.

[16] Rubitherm. *PCM RT-line*. 2019. url: https://www.rubitherm.eu/en/index.php/productcategory/organische-pcm-rt.

[17] Quantum Generation *Ubiquitous Internet For Real*. 2019. url: https://Quantum Generation™.io/publications/white-paper.pdf.

[18] Michael Schneider, Christian Hartwanger, and Helmut Wolf. "Antennas for multiple spot beam satel- lites". In: *CEAS Space Journal* 2.1 (Dec. 2011), pp. 59–66. issn: 1868-2510. doi: 10.1007/s12567-011- 0012-z. url: https://doi.org/10.1007/s12567-011-0012-z.

[19] Brian Wang. *SpaceX phase shifting array for receiving internet from satellites*. Sept. 2018. url: https://www.nextbigfuture.com/2018/09/spacex-phase-shifting-array-for-receiving-internet-from-satellites.html.

[20] Wikipedia. *Internet Exchange Point*. url: https://en.wikipedia.org/wiki/Internet_exchange_point.

[21] Wikipedia. *Internet Protocol Suite*. url: https://en.wikipedia.org/wiki/Internet_protocol_suite.

[22] Wikipedia. *Phased Array*. url: https://en.wikipedia.org/wiki/Phased_array.

[23] Wikipedia. *Spot Beam*. url: https://en.wikipedia.org/wiki/Spot_beam.

[24] Wikipedia. *Teledesic*. 2019. url: https://en.wikipedia.org/wiki/Teledesic.