Contract Structures for SatCom: How will Competition from LEO Mega Constellations Change How Communications Services Are Purchased?

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1.0 Abstract

Communication Satellite Operators contract their capacity through Service Level Agreements (SLAs) to their customers, some of which reserve fixed capacity over multiple years. Relative to current capacity constraints, this market has seen substantial demand growth, as well as number of new entrants such as SpaceX and Amazon. While historically these SLAs have helped matched large capital investments with long term revenue, the history of communications markets suggests that this leaves significant capacity and revenues underutilized. Our objective is to review existing SLAs, identify their limitations, and explore new SLAs, some of which leverage the flexibility of new communication satellites. We find that existing SLAs can be characterized into Classical, Data Volume, and Dual SLAs. While important historically, these are found to leave significant capacity and revenue potential underutilized while simultaneously failing to meet customer desire for improved flexibility and lower prices. Through 60 interviews with satcom customers, we find that lower prices and more flexibility for capacity bookings are the two most desired characteristic. By examining the history of the cloud computing and telecommunication industries, we propose Spot Instance, Time-of-Day Pricing, and Two Classes of Service SLAs, which address these shortcomings by offering more liquid services accessible to a broader range of customers. We conclude that the Classical SLA excels where reliability and speed are essential, traffic volume is high, and variation is low. When consumers are price-sensitive, data volume SLAs, Time-of-Day Pricing SLAs, and Two Classes of Service SLAs are affordable options. When the traffic patterns are not repeating on a daily or monthly basis, spot instances offer the desired flexibility.

2.0 Keywords:

Communication satellites, market segmentation, service level agreements

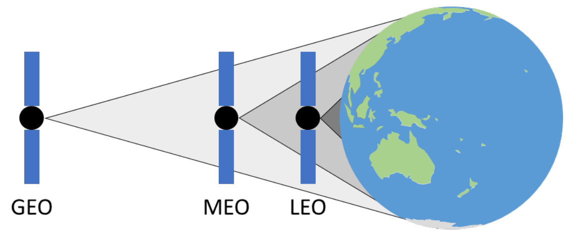
3.0 Introduction

Substantial new entrants to the communications satellite market (SpaceX, Amazon's Kuiper, OneWeb, and Telesat among them) will create significantly more competition[1–3]. With increased supply, in the presence of growing demand, it is likely that there will be price competition, but it is also possible that players will seek to differentiate on ease of doing business. Satellite internet services are defined by Service Level Agreements (SLAs), a purchasing contract for telecommunications that specifies the promised data rates, uptime, and other operational details along with the pricing. The structure of SLAs has remained unchanged for decades despite the anticipated increase in both demand and competition[4,5]. Current contracts take weeks to months to negotiate, and lack many of the common variations (spot markets, time of day pricing, etc.) found in other large infrastructure sectors. How Communication Satellite Operators may develop and utilize novel SLAs to meet these challenges and opportunities is an important – yet unexplored - area for investigation.

The objective of this article is to identify and evaluate novel SLAs for use by communication satellite providers in the era of new space.

Background

The history of commercial satellite communications is a steady drive from typically unidirectional geostationary Earth orbit (GEO) to bidirectional low Earth orbit (LEO) services with a corresponding increase in data rate and uncertainty in usage characteristics[3,6]. As shown in Figure 1, LEO is characterized by low latency but with only small coverage per satellite, while GEO has high latency with large coverage areas. Medium Earth Orbit (MEO) is correspondingly in the middle of this range.



	GEO	MEO	LEO
Altitude	35,786 km	10,000 km	500 km
Latency	238 ms	67 ms	3 ms
Relative field of view	Hemisphere	Continent	Country

Figure 1: Major orbits with parameters affecting satellite communications. This is one example of a potential configuration but (in MEO and LEO) a range of values are possible.

One of the traditional roles of satellite communication was for unidirectional broadcasting of video content such as direct-to-home television. Here, a known number of channels is broadcasted constantly with no change in downlink data rate. Satellites operated primarily from GEO since the associated 238 ms round-trip light-speed delay does not negatively affect unidirectional broadcasting. These satellites cover a large area while remaining constantly in view for observers on the planet – making receiving broadcasts from these satellites inexpensive and reliable. After the launch of Intelsat I in 1969, with a data throughput equivalent to one television channel[7,8], advancements in launch vehicle technology allowed for heavier payloads with hundreds of stations[9].

One of the biggest historical bidirectional communications deployments came in the 1990s with companies such as Iridium, Globalstar, Orbcomm, and Teledesic[10–13], which focused on talk capabilities with limited broadband capacity. In a bidirectional system, data can be sent between users and terminals with the orbiting satellite as an intermediary, such as for transcontinental telephony backhaul. These 1990s bidirectional networks employed large constellations of LEO satellites to reduce latency, though at the cost of requiring more satellites to cover the same area[11]. Technological problems and encroachment of ground-based cellular networks limited the success of these early attempts[10–13]. The scope of this paper excludes these early bi-directional systems operating fixed satellite service (FSS) and early mobile satellite services (MSS) given their low data rates in modern terms – this paper is scope to the modern “high throughput satellite” market, which provide at least 2-20x the throughput.

Over the last decade, consumption has shifted from broadcasted content towards on-demand streaming, resulting in a shrinking satcom broadcasting sector. In response, the satellite communications industry is moving toward bidirectional broadband internet coverage through digital communications payloads with multi-beam phased arrays. One such network is the O3b mPower constellation consisting of seven MEO satellites with a combined throughput of over 1 Tbps[14,15]. As shown in Figure 1, MEO provides these satellites with good coverage and acceptable latency.

Establishing MEO constellations are extremely expensive, requiring from 10 to 100 satellites, which alone can cost US$140 million per unit[16]. One way of reducing financial risk to both operators and customers is entering long-term SLAs where price and level of service – including performance monitoring and repercussions for failing to meet an agreed standard – are set in advance[17]. Investors are more willing to expend significant capital investments due to reduced risk on returns over a shorter period. These investors will also demand less return to compensate for similarly low risk, which increases the capital funding potential of the endeavor.

Key components of an SLA are:

- Service: A description of the service, including potentially telephony, data transmission, or access to the internet, as well as the specific radio frequency or set of frequencies and user terminal required.
- Performance: Characteristics of the service such as desired internet bandwidth and percentage uptime of the connection. Another measure of this service is the Committed Information Rate (CIR), an agreement for some minimum Mbps data rate available. An agreement may be for a CIR of 10 Mbps for service availability of at least 99.99% of the period. This is equivalent to 4 minutes of downtime each month.
- Monitoring: Performance is monitored automatically with an agreed process in place for contacting the operator if this falls below the agreed level.
- Repercussions: If the performance falls below the specified level for more than a certain time, the Operator pays some penalty. For example, if the data rate falls below 10 Mbps for more than 4 minutes in a month, the Client may be entitled to a discount for that period[18].

With the now proven demand for satellite-based internet services, new commercial companies are entering the market. Exponential growth in the industry driven by especially high growth in the mobility sector – such as airplanes, maritime, trains, trucks, automobiles, and Unmanned Arial Vehicles (UAVs) - is predicted[19–23]. Since 2016, the Federal Communications Commission has received 11 applications from commercial companies for new high-throughput non-geostationary satellites[24], specifically low latency LEO constellations, such as from Telesat[25], OneWeb[26], and SpaceX[27]. Due to the small individual coverage area of each satellite, these networks may eventually contain up to 30,000 total satellites[27].

The effect of these changing conditions is not yet known. Some established players, such as SES and ViaSat, are expected to launch dedicated broadband satellites[28,29], while others, Globalstar and Iridium, have made no public statements about a shift in strategy. Since 2016, one major player, Amazon, has entered, while two others, LeoSat and OneWeb, have filed for bankruptcy, which serves to emphasize the uncertainty of operations in this field.

The specific objective of this article is to qualitatively examine SLAs and their appropriateness in the new era Satellite Communication era. This article will begin with a literature review exploring how SLAs have traditionally been developed and implemented within adjacent industries. After reviewing traditional SLAs, we will then describe our own approach, following its implementation through the challenges and opportunities presented to both operators and customers. Novel SLAs will be synthesized and examined for their usefulness to both operators and customers, with conclusions drawn about when, how, and if they should be implemented.

4.0 Literature review

A widely accepted approach to identifying the challenges and opportunities faced within an industry is through market segmentation. Customers are divided into broadly similar groups, targeted through group-customized product offerings. In 1982, Elrod and Terry[30] empirically showed that profit could be substantially improved by aggregating customers into distinct market segments and using differential pricing for each. Plank[31] also highlights the importance of market segmentation as a tool for resource allocation within a business. Although multinational corporations traditionally would perform segmentation within each country, Yip[32] showed that from the early 1990s onwards, such distinctions were becoming less important. Freytag and Clarke[33] examine industry practices to first determine whether a certain segment should be targeted with a specialized product. They indicate that the segment must be of sufficient size, growth potential, and profitability to compensate for added risk and resources required by adjusting strategy to target that segment.

Research into market segmentation for satellite communications is limited, although various authors have interrogated similar problems from the perspective of telecommunications. Bolton and Myers[34] used data from several large telecommunications businesses operating internationally to demonstrate that market segmentation is profitable in this domain. Bayer[35] examined real-world data to compare Customer Value Segmentation, Customer Behavior Segmentation, Customer Life cycle Segmentation, and Customer Migration Segmentation. She concludes that each method is important and should be considered together, ultimately recommending that each customer themselves be considered a micro-segment.

The processes required to perform segmentation are well studied. A common strategy amongst researchers[36–40] is to conduct a large number of consumer interviews and then use cluster analysis to identify market segments based on the responses. Ter Hofstede et al.[41] used the Bayes model of segmentation for business-to-consumer marketing within the meat industry. The team surveyed 2000 customers, dividing them into five distinct segments. Kuo and Chien[42] used Monte Carlo analysis to explore the effectiveness of commonly used segmentation techniques using artificially-generated survey data from a simulated telecommunications market. The pair found that using self-organizing feature maps to identify an appropriate number of clusters, followed by genetic algorithms to find the final solution is a robust method for this sort of problem. Where surveys are not possible, qualitative approaches are considered. Hague and Harrison[43] examined how companies across a range of business-to-business industries conduct segmentation without the use of surveys. Simple approaches of convenience by geography and language were well developed. Firmographics -company size and products made - and behavioral - sensitivity to price and quality – were more complex to implement but produced better results.

Preliminary segmentation of the satellite communications hinges on the ITU regulation[44], which keys on where the client is located. The key categories are fixed-satellite and mobile-satellite services with further mobility subdivisions in land, maritime, and aeronautical. NSR[45,46] and Euroconsult[47] further segment the market into the client’s operations sector, suggesting seven major categories for satellite communicators. Consultancy firm Grand View Research[48] divides the global satellite communications market based on application.

SLAs have long been of research interest, although much is left unexplored. This is especially true in the field of satellite communications.

While little work in writing new forms of SLA has been conducted, there is significant interest in how to apply and adapt existing forms to the communications industry. A patent by Dube et al.[49] provides instruction on the design of SLAs for data centers which aggregates predicted and existing user demand to set prices and level of service optimally. Kolia et al[50] describe how software platforms such as GRIA are used to implement this technique. Byde et al. [51] take a more fundamental approach to the topic by simulating a market-based resource allocation system on which agents must bid on. Some level of market segmentation is employed but only into three service tiers rather than by industry or behavior assignment. Although Aib et al[52] propose a generalized SLA generation tool for business-to-business applications, it does not itself suggest a new model, only how new SLAs should be negotiated.

Another focus of current SLA research is on how to meet the agreed targets by efficient allocation of resources. This makes sense since maintaining current SLAs as a business takes on more customers is an important part of growth. Nair and Bapna[53] apply Markov Decision Processes originally developed for airline and hotel bookings to the field of internet service providers, ensuring that SLAs for agreed uptime are met. Zhu and Singhal[54] explore an optimization problem resource assignment for internet data centers again to meet SLA demands.

Research into the generation of entirely new SLAs is limited. One exciting area of SLA research is Green SLAs (GSLAs) which incorporate environmental impact into a standard SLA agreement. Ahmed et al[55] explore GSLAs by first identifying limitations of existing SLAs, such as missing performance indicators relating to the environment, as well as demands of the customers that must be met. They then describe the design of GSLAs which could meet these requirements and suggest that future research should be done into modeling the tangible effects of the new GSLAs. Rather than generating entirely new business ideas from scratch, Kaissi[56] examined the process of cross-industry learning where tools and practices originating in telecommunication and aviation were adapted for use in healthcare. He noted that this diffusion occurs naturally, starting with a limited number of early adopters, with the technique spreading through consultants. He finds that the trend is not isolated only to medicine. Byron and Roering[17] qualitatively explore how strategic practices in the private sector can be applied to the public, concluding that while this ‘cross pollination’ should be embraced, it must be done carefully to ensure that the techniques used are tailored to fit rather than taken directly. The team examines six strategies with varying levels of suitability for transfer.

From this literature review, we may infer that while much research has been conducted into market segmentation and SLAs, we have not yet used market segmentation to derive SLAs for the communication satellite industry. It is important to reconsider existing SLAs since, while the industry has undergone considerable change, the SLAs used have not.

5.0 Method

An appropriate experimental method was developed from the literature previously described.

Segmentation

First, the satellite communications market was segmented. Three bases were used to segment the market. These were selected to serve as a proxy for the interview questions described by other researchers[36–40] and considered the most important to identify when breaking down a customer base.

Type of business makes explicit what business is behind the “type of customer” as used by NSR[45,46] and Euroconsult[47]. For example, their type “consumer” implies that it is mostly one single end-user. In contrast, “maritime” can be a single terminal consumer, multiple terminals business, a service provider, or a government customer. With our basis, this separation becomes explicit.

Mobility type aligns with the “type of customer” basis of NSR and Euroconsult. The customer can be in the air, in the sea, or on land – we only care about if and how fast they are moving. In this distinction, a cargo ship is more comparable with an airplane than a fixed energy platform in the Atlantic since the platform can be serviced by the same satellite over the lifetime of the contract, whereas both the ship and airplane will move which might require connecting to a new satellite– a much more onerous requirement for the provider to fulfill.

Usage per terminal defines the average throughput of the customer. Higher usage customers usually have larger terminals and will rely more heavily on this service for their business operations.

Challenges and opportunities

Next, the challenges and opportunities faced by both suppliers and customers were identified.

A series of 60, 45-minute interviews with existing communication satellite business customers was conducted. All were customers of a single large international operator but were drawn from a range of geographies, industries, and satcom services requested. 17% of interviewees were from Sub-Saharan Africa; 15% Middle East and North Africa; 8% Latin America; with the remaining 24% preferring to remain anonymous. Satcom services requested were 35% very small aperture terminal (VSAT), 13% mobile (including ships and airplanes), 11% internet service providers, and 5% broadband wireless access. The interviews explored:

A. Identifying the customer’s industry and how they currently use communications satellites.
B. Discussing how they intend to change their operations in the future.

C. How price (subscription and equipment cost) affects the customer's decision-making at purchasing more capacity.
D. How quality of service (latency, availability, ground-terminal requirements) affects the customer's decision-making when purchasing more capacity.

Given that the interviews were only conducted by a single operator, their generalizability is limited. Further, as these only represented current customers, not future potential customers, there is an anchoring bias in their responses. A first-principles approach was taken to identify additional operator-based challenges. A hypothetical 24-hour window was examined. Within this analysis, the standard unit of comparison will be power. This is because while current SLAs may be written in terms of Mbps, the real limiting factor is the power which can be allocated. For example, a user may have contracted 100 Mbps which demands 5W of power if the customer is located at the equator and under clear skies but 8W if they are in the Mediterranean during a storm where there is greater atmospheric loss. Similarly, if the customer is using less than their allocated 100 Mbps, then there may be less than 5W of power demanded. For the sake of analysis, we'll assume that the maximum allocation required for 100 Mbps is 10W and that the maximum power budget for a satellite is 100W. This is informed by the link equation but with larger, more "round" numbers to help illustrate the concepts.

SLAs

Finally, a range of SLAs are examined for their ability to meet these identified challenges and opportunities. This involved a three-step process:

A. Assessment of existing SLAs used within the communication satellite industry.
B. Exploration of existing SLAs used within similar businesses of cloud services and telecommunications. These were then investigated to see if there was a direct equivalence with communication satellite SLAs.
C. Where equivalents did not exist, novel SLAs were adapted to suit the communication satellite industry and then examined to determine how their inclusion in a provider's offering could improve operations and profitability. Both traditional and novel SLAs were examined for suitability within each of the industries, and conclusions about when each should be implemented were drawn.

6.0 Results

6.1 Market segmentation

As illustrated in Figure 2 segmentation of the market provided 12 different segments.

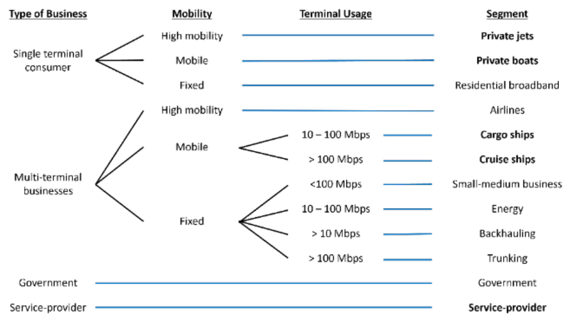


Figure 2: Market segments. Categories not already defined by NSR[45,46] and Euroconsult[47] are shown in bold.

This basis affirmed segmentation by NSR[45,46] and Euroconsult[47] while also suggesting several new categories. Segments are described in Table 1. Several factors per segment are noted, namely the required (or constrained) user terminal size, the data usage, and the segment's vulnerability to displacement by fiber and 5G network rollout.

Table 1: Comparison of key customer categories including terminal and data characteristics

User	Description	Terminal	Data Usage	5G & Fiber Displacement Vulnerability
Airlines	Airlines services provide broadband connectivity to the passengers onboard a commercial aircraft. These passengers are multiplexed and perceived as a single customer by the satellite.	0.6 – 1.2 m dish Remote Moving terminal	10 – 100 Mbps High variation	None
Backhauling	Backhauling connects a subnetwork, such as a cellphone tower in developing country, with the fiber backbone of the internet.	1.2 – 4.5 m dish Rural Fixed terminal	> 10 Mbps Medium variation	Significant Displacement Vulnerability
Cargo ships	A subset of maritime characterized by small-medium sized crews with lower data requirements.	1.2 – 2.4 m Remote Moving terminal	10 – 100 Mbps Medium variation	None
Cruise ships	A subset or maritime characterized by large crews and passenger count demanding access to the internet.	1.2 – 2.4 m Remote Moving terminal	> 100 Mbps Medium variation	Potential Displacement Vulnerability
Energy	Oil and gas offshore customers where satellite communication is the only option. Traffic volume varies based on the size of the operation.	1.2 – 2.4 m Remote Fixed terminal	10 – 100 Mbps Medium variation	Potential Displacement Vulnerability
Government	Government is the broadest segment with aspects of all users described since the terminals can range from small sizes on UAVs to larger terminals on a remote base. Unique contracting and security requirements make this a separate group.	Varies	Varies	Low Displacement Vulnerability
Private boats	Small vessel operating base on an individual's demand. Experience high variation due to seasonality such as during vacation time.	0.6 – 1.2 m dish Remote Fixed terminal	<100 Mbps High variation	Low Displacement Vulnerability
Private jets	Small aircraft operating based on an individual's demand for travel. Experience high variation due to varying flight schedules.	0.6 – 1.2 m dish Remote Moving terminal	<100 Mbps High variation	None
Residential	Residential broadband addresses a single terminal consumer to connect their house with the internet especially in remote regions with limited or no wired internet.	0.6 – 1.2 m Remote Fixed terminal	< 100 Mbps High variation	Significant Displacement Vulnerability
Service-provider	Requirements vary based on what segment the provider operates in and the products they sell.	Varies	Varies	Potential Displacement Vulnerability
Small-medium business	Businesses operating in remote regions or with the need for high-reliability connection not met by wired connection. Most use multiple terminals.	0.6 – 1.2 m Urban & remote Fixed terminal	< 100 Mbps Medium variation	Significant Displacement Vulnerability
Trunking	In Trunking, Satellites are used to supplement wired networks experiencing temporary spikes in demand. Multiple end-customers are multiplexed which reduces variation. A subset of trunking customers are willing to pay these premiums since satellite provides additional data security and connection reliability.	2.4 – 4.5 m Urban Fixed terminal	> 100 Mbps Low variation	Potential Displacement Vulnerability

6.2 Challenges and opportunities

6.2.1 Consumers

Analysis of the 60 interview transcripts revealed that the following characteristics as very important to customers:

1. Lower prices so that satellite providers are competitive with terrestrial alternatives
2. Increased flexibility of capacity to offer end users a wider range of service types.
3. Lower connection latency, although it was noted that this does not limit growth as end-users are developing technologies to deal with high latency.
4. Reduced barriers to entry through reduced cost of terminals.
5. Better customer support.

This analysis will just consider the first two since customers considered these to be the most important.

Lower pricing of internet service is essential as customers view satellite communication as a last resort – only being employed where higher reliability and lower cost (both upfront for the terminals and as a subscription) options such as fiberoptic and cellular networks have not yet been rolled out. Satellite internet is expensive, and customers will switch providers if cheaper options are available. To achieve this lower price point, operators must reduce their prices which is only sustainable if their costs also fall. Higher utilization of existing networks will reduce prices as the same costs are able to be spread over a greater number of customers. Thus, customers have an incentive to support the operator in achieving high utilization.

Increased capacity flexibility allows operators to offer their end-users custom SLAs, distinguishing themselves from the competition. This requires shorter contract durations or the ability to modify contracts to respond to changes in end-user demand.

6.2.2 Operators

A key challenge facing operators is unused capacity. If a satellite has a maximum power capacity of 100W, but only 40W are used, then there is 60W of unrealized potential for the network. If the operator currently has an income of $10M, utilizing the total capacity should result in an additional $15M income. From an operator's perspective, a key challenge is increasing capacity utilization.

To fulfill a Classic SLA, the service provider will allocate only so much capacity so that all CIRs can be met simultaneously. As a basic example, our operator may have a satellite that supplies the customers for a region and has a maximum power capacity of 100W. It offers ten SLAs, each with a 100 Mbps CIR each of which will demand a maximum of 10W each, thus fulfilling a full 100% capacity. However, each customer may not always require the full 10W. We will model the actual power demanded by each customer as a continuous uniform distribution from 0 to 10 W. Figure 3 shows that there is some variation over the period of used capacity; however, it never reaches the maximum permissible 100W capacity. Thus, there is some full-day available capacity that is never utilized.

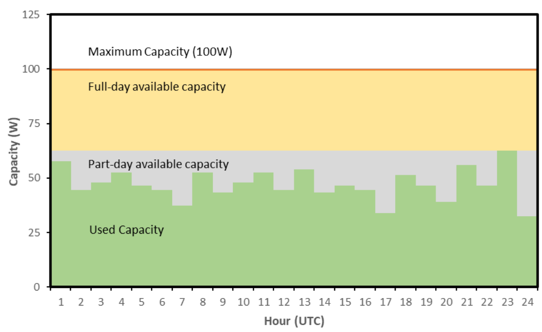


Figure 3: Conceptual view of the used, available full-day and part-day capacity for continuous random usage from 0 – 10W for 10 customers. Noe that used capacity never exceeds 60W.

An operator may wish to overbook some of their capacity, relying on the fact that it is unlikely for multiple users to demand their full CIR simultaneously. In this study, we assume that the operator, having observed that the maximum used capacity from the previous example never reached above 60W, has invited six additional customers. The same simulation was run but now with 16 customers. As shown in Figure 4 this has resulted in a brief window where customer demand exceeded the maximum capacity of the satellite. This is impermissible with a Classic SLA, and the operator will suffer a financial penalty in addition to potentially damaging their reputation. This issue cannot be resolved until the multi-year SLA terminates.

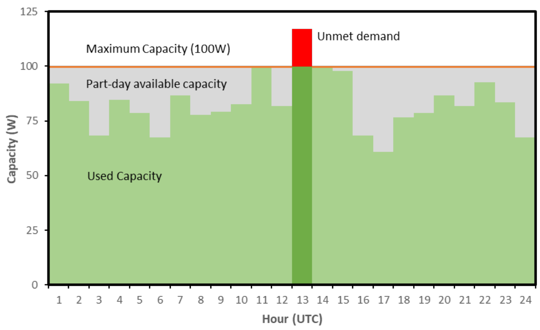


Figure 4: Conceptual view of the used and part-day capacity for continuous random usage from 0 – 10W for 16 customers. Note that there is unmet demand at UTC 13.

Analysis of the customer segments highlights an even more extreme issue of unmet capacity with a high variation in the amount of data required over the course of the day. While business customers have peak hours between 9am to 5pm and residential users peak during the evening both exhibit strong diurnal variation. The effects of introducing this variation using a time-dependent sinusoidal factor are depicted in Figure 5, where an even more extreme part-day available capacity issue than in Figure 3 can be observed.

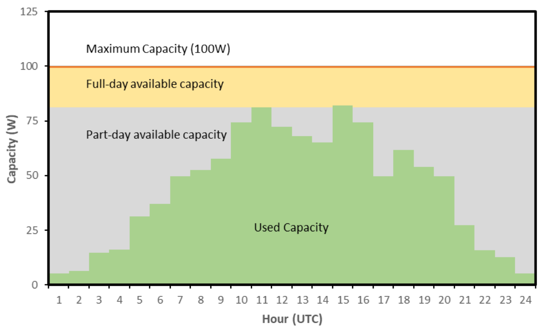


Figure 5: Conceptual view of the used, available full-day and part-day capacity for time-dependent random usage from 0 – 10W for 16 customers.

6.3 Appropriate SLAs

Based on the preceding challenges, the key requirements which SLAs must meet are:

- Achieve lower prices,
- Allow flexible capacity allowance,
- Provide safe overbooking by the operator, and
- Promote smoothing of diurnal variation.

6.3.1 Existing SLAs

Within the satellite communications industry, there are three primary types of SLAs. These are summarized in Table 2.

6.3.2 Novel SLAs

By studying SLAs from industries similar to satellite communication, we can identify gaps that could be met by novel SLAs.

Cloud services provide users with access to additional computational functionality, such as resources or application hosting, via the internet. Due to heavy reliance on the internet and similar profile of large establishment costs with a finite capacity which must be allocated to the client, it is a useful analogy to satellite communications. Table 3 provides a comparison between typical cloud service SLAs and their equivalence in satellite communications.

Telecommunication relates to the transfer of information across a network. Often telecommunication providers are the clients of communication satellite operators. Some of the key offerings are summarized in Table 4.

Based on these offerings, three novel SLAs without a communications satellite equivalent are examined in Table 5.

Table 2: Comparison of Existing SLAs

SLA	Description	Example	Monthly Revenue	Source
Classic	An agreed-upon CIR is supplied. Price per Mbps, p_{CIR}, is defined with higher CIR costing more.	Client pays $1000/month for 36 months in exchange for a CIR of 10 Mbps over the period.	$p_{CIR} \cdot CIR$	57–59
Data Volume	A fixed amount of data volume, V, per month is provided with no fixed speed. Price per GB, p, is defined. Once this data is used connection is revoked.	Client pays $1000/month for access to 100 GB of data each month over the period of 36 months.	$p \cdot V$	57–59
Dual	A combination of Classic and Data Volume SLAs where a limited volume of high-speed and unlimited low-speed bandwidth are provided.	Client pays $1000/month for 36 months for 50 GB of high-speed internet and unlimited 10 Mbps.	$p_{CIR} \cdot CIR + p \cdot V$	57–59

Table 3: Comparison of Cloud service SLAs and their satellite communications equivalent when such an equivalent exists. Costs are for June 2019 from Amazon Web Services[60] a1-medium product offering.

SLA	Description	Equivalent traditional SLA	Source
Dedicated hosts	The client purchases physical infrastructure which they have exclusive use of for the lifetime of the infrastructure. Pricing was not directly available.	This is similar to a MHz-based Classical SLA for the duration of the satellite's lifetime.	60
On-Demand	Customers pay per hour with no commitments as to how much or little is used. It is the most expensive of the SLAs offered. Example cost of $0.0049/h.	There does not appear to be a direct equivalent.	60
Reserved instances	A certain capacity is reserved. These computational resources are not shared with other clients with a standard contract of 1 year at $0.00294/h or a 3-year contract at $0.00196/h.	Similar to Classical SLAs.	60
Spot instance	Spot instance prices are modified based on demand and capacity. If demand increases unexpectedly then AWS can terminate an instance at any time. Low prices are used to encourage customers with non-urgent processes using capacity at off-peak times. It also prevents maximum capacity from being exceeded. An off-peak cost of $0.0049/h was observed.	There does not appear to be a direct equivalent.	60

Table 4: Comparison of Telecommunication SLAs and their satellite communications equivalent when such an equivalent exists.

	Description	Equivalent traditional SLA	Source
Best-effort service	The network tries to provide the best possible service but with no guarantees. It will be best during off-peak times and worst when demand is highest.	There does not appear to be a direct equivalent.	[61]
Guaranteed service	The provider delivers a service only if the client's traffic is within certain constraints. This comes with a quality-of-service guarantee which implies that some resources are reserved for the client's dedicated use as needed.	This is very similar to a Classic SLA with a CIR.	[61]
Combined guarantee and best-effort service	A combination of best-effort and guaranteed. Traffic up to a certain volume receives a guarantee with any traffic that exceeds this volume delivered as a best-effort service. Priority traffic can be sent through the best-effort service with non-priority through the best-effort.	There does not appear to be a direct equivalent.	[61]
Minimum guaranteed and uncertainty	Customers from a defined pool share capacity with each customer receiving some minimum service and any additional available capacity being shared as required on a best-effort format. This can promote 'negative externality' or 'tragedy of the commons' problems.	There does not appear to be a direct equivalent.	[61]
Time-of-day pricing	A best-effort service where demand is communicated through a change in price depending on when the service is access. For example, lower costs at off-peak periods at nighttime. This is regulated through fair use policies.	There does not appear to be a direct equivalent.	[61]

Table 5: Summary of proposed novel SLAs including any additional technology required and how they meet the desired characteristics outlined previously.

SLA	Description	Additional technology	Characteristics
Spot instance *Inspired by cloud services "spot instance"*	Based on cloud service spot instance model with short term contracts. Either side can terminate at any time which increases customer flexibility and allows the provider to overbook. This SLA is ideal for clients who want additional capacity, occasional use customers, or customers serviced by another operator but who need a short-term capacity increase. Monthly revenue is $\Pi = p_{spot} \cdot CIR$.	Due to the more frequent contracting through spot instances the capacity allocation should be automated through a dynamic resource management system.	✓cost ✓flexible ✓overbooking ✗smoothing
Time-of-day *Inspired by telecommunications "time-of-day pricing"*	Longer-term contracts focused on smoothing out diurnal variations with higher prices during daytime peaks and lower prices at night. Price-sensitive customers will attempt to shift traffic to cheaper hours of the day but may alternatively switch to another operator, while price-insensitive customers will accept this price and benefit the provider with additional revenues. Price discounts may be required to prevent customers with traffic that cannot be shifted from abandoning the provider. Monthly revenue is $\Pi = \sum_t p_t \cdot CIR_t$.	Depending on the nighttime usage increase and orbit characteristics this may require more powerful satellite batteries to facilitate capacity smoothing.	✓cost ✗flexible ✗overbooking ✗smoothing
Two classes of service *Inspired by telecommunications "combined guarantee and best effort service"*	Longer-term contract focused on smoothing out diurnal variation. Required real-time traffic operates similarly to a Classic SLA agreement whereas not-real-time is charged accordingly to a data volume SLA where service may be restricted during peak times. Monthly revenue is $\Pi = p_{CIR} \cdot CIR + p_{not-realtime} \cdot V_{month}$.	Requires deep packet inspection to determine which data belongs to which service category and act accordingly. May benefit from IPv6.	✓cost ✗flexible ✓overbooking ✓smoothing

6.3.3 Analysis

A qualitative assessment for each segment as to their most appropriate SLA is made below and summarized in Table 6.

Airlines have multiple airplanes in constant use with defined flight schedules. Due to this repeating pattern, spot instances are impractical. End users only connect to the service for brief periods of time; thus, separating service by the hour is similarly suboptimal, although it can help smooth out usage. Data volume is useful to cover the passengers demand, although dual will always guarantee some level of service, which may be required for operations.

Backhauling connects many customers together, which reduces variation and makes Classic SLAs a good fit. End users are residential customers and small businesses and thus have high price sensitivity, which makes time-of-day pricing and two classes of service attractive options.

Cargo ships have usage behavior similar to that of residential and business users with predictable diurnal variation making time-of-day pricing an attractive option to shift demand. Users are less price sensitive, which makes this a good way of maximizing revenue, although at the cost of potentially driving some customers away. Two classes of service may be one option to facilitate business and personal data usage.

Cruise ships have very strong seasonality in addition to diurnal variation. Many customers with similar behaviors are routed together to magnify traffic spikes from, say, sharing media from a special event or interesting sighting. Spot instances can be a good addition to classic SLAs to help cover these spikes.

Energy customers have similar usage behavior to residential and business customers. Due to additional reporting and communications requirements and price insensitivity make classic SLAs attractive due to guaranteed consistent service.

Government has relatively stable and consistent demand. Government generally has low price sensitivity, which make many tools for adjusting behavior impractical. Two classes of service are not possible for government customers due to additional security requirements, which excludes deep packet inspection.

Private boats have very high seasonality and strong diurnal variation. Therefore, the Classic SLA is a particularly poor fit. Data volume may help to smooth usage over a monthly period but does not offer the speed guarantee demanded by this customer segment. Occasionally used boats would benefit from the short-term flexibility of spot instances. Longer trips would benefit from two classes of service format to keep prices low.

Private jets are comparable to private boats, although time-of-day pricing is likely to be even less effective at modifying user behavior due to the price insensitivities of this customer segment.

Residential broadband is always connected with predictable daily and weekly variations. Since users are price sensitive, time-of-day pricing can be an attractive offer. Due to this repeated, long-term usage spot instances are unlikely to be attractive, while Classic SLAs will remain useful. Since minimum speed requirements are lower for residential than other customer segments, data volume SLA is also a good fit.

Service providers operate within a range of markets, making assessing their best SLA types more challenging. They can create their own incentive schemes to model their own customer behaviors to best match the SLA they are partaking in. Spot instance SLAs may be an attractive tool for allowing the provider to test out a range of new offerings to their customers.

Small-medium businesses have very high diurnal variation, with data use almost exclusively during business hours. It is often important that such communication be reliable and fast, making time-of-day pricing a poor fit. If deep packet inspection is implemented, then two classes of service could ensure that time-sensitive data is communicated swiftly, leaving less important data to transfer during off-peak times.

Trunking is the segment with both the highest and smoothest traffic. The classic SLA with ensured CIR is a favorable choice, and so can be a two-classes of service that separate real-time from not real-time with a more attractive price in return. Trunking is often used as a backup to terrestrial networks and will thus experience a temporary unplanned increase in demand. This could be met using spot instances.

Table 6: Assessment of the fit of the six SLAs in the identified key customer market segments.

Segment	Classic	Data volume	Dual	Spot	Time-of-day	Two classes
Airlines		✓	✓			
Backhauling	✓		✓			✓
Cargo ships			✓		✓	✓
Cruise ships			✓			✓
Energy			✓		✓	✓
Government	✓	✗		✗		
Private boats	✗		✓	✓		✓
Private jets	✗		✓	✓	✗	
Residential broadband		✓	✓	✗	✓	✓
Service-provider			✓	✓	✓	✓
Small-medium business			✓			✓
Trunking	✓	✗		✓		

7.0 Conclusion

SLAs have played an important role in contracting capacity and facilitating long-term investment in high-cost satellite communication projects. New market entrants and changing customer demands necessitate the exploration of novel SLAs. Key market segments were identified, and representatives were interviewed to determine what these SLAs should entail. Similar markets of cloud computing and telecommunications were reviewed to highlight areas that are missing.

Novel SLAs suggested were spot instance, time-of-day, and two classes of service. These can be added to a service provider's traditional classic, data volume, and dual SLAs.

This paper shows that classical SLA excels where reliability and speed are essential, traffic volume is high, and variation is low. When consumers are price-sensitive, data volume SLAs, Time-of-Day Pricing SLAs, and Two Classes of Service SLAs are attractive options. When the traffic patterns are not repeating on a daily or monthly basis, spot instances offer the desired flexibility.

Recent events in Satcom suggest there may be new opportunities to introduce novel SLAs. SpaceX's Starlink constellation applied for and was initially granted a roughly $1 billion subsidy from the Rural Opportunities Development Fund. However, this was later overturned by the FCC (which SpaceX has appealed), as the FCC judged the data rates provided did not meet their minimum standards set by the government's SLA terms for this subsidy.

Future work in this field demands quantitative analysis to determine how the implementation of the recommended SLAs into each of the identified segments will serve to benefit the provider and their customers. This could be facilitated through simulation-based approaches.

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