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Ground Systems Requirements for Software Defined Satellites

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by Elisabeth Tweedie

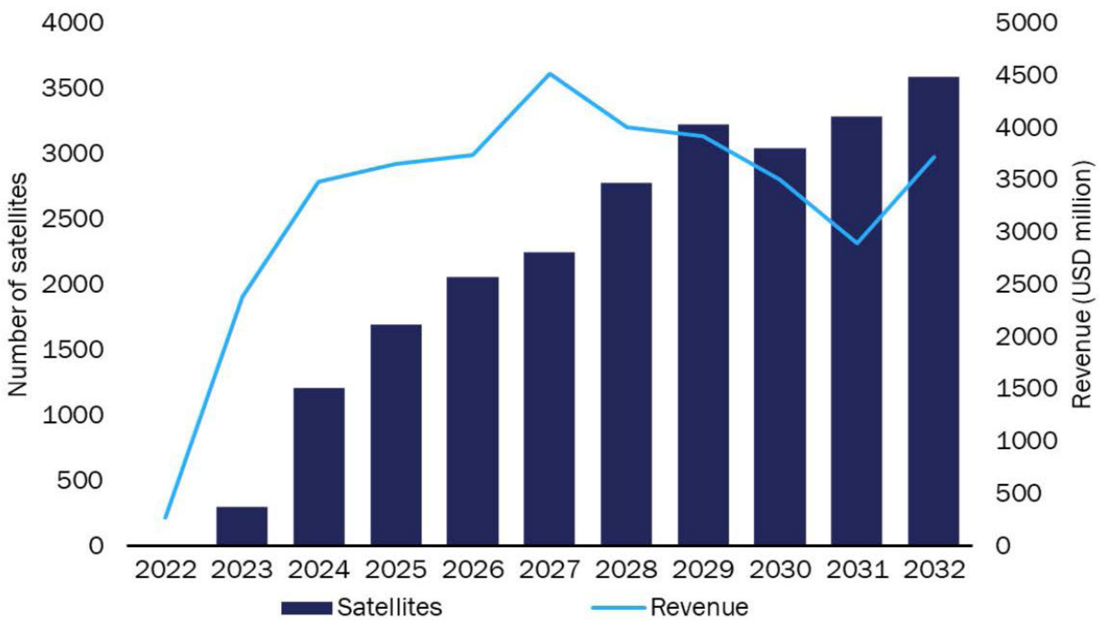
The satellite ecosystem has been going through a period of tremendous change and growth over the last few years. According to Euroconsult (now known as Novaspace), the global space economy grew over 34% in the five years to 2023 to be worth US$ 509 billion and is projected to continue growing to reach US$759 billion by 2030. A lot of this growth is attributed to "New Space," a generic term, referring to the rapid changes taking place in the satellite ecosystem.

The success of low earth orbit satellites (LEOs), Starlink in particular, has had a significant impact on the industry. Mark Dankberg, CEO Viasat put this succinctly, when he stated during the World Space Business week earlier this year, "The industry is going through a period of quantum change, unlike anything I have seen in the last 40 years." But it's not only LEOs that are shaking up the industry. 5Gpresented the opportunity for satellite to integrate more closely into the telecom infrastructure.. At the same time changes in technology both on orbit and on the ground are having a major impact.

Historically, one of the major limitations with satellite communications, was that a geostationary orbit (GEO) satellite would be built to provide a particular service in a particular area, the footprint would be fixed, as would the technology utilized. But that satellite would be on orbit for 15 plus years. During that time, customer needs would likely change, and the terrestrial telecom ecosystem would most certainly have changed, both in its reach, as more fiber and cellular networks were deployed, and in its capabilities, as technology improved. Software-Defined Satellites (SDS) offer an unprecedented level of flexibility and capability for satellite operators. Reconfigurable payloads mean that beams can be reshaped and steered on demand, frequencies can be changed and reallocated as needed and services adapted in real-time. Onboard technology can also be updated, as required. A true game-changer for the industry.

SDS are not just for GEOs, the new low-earth and medium-earth orbit (LEO and MEO) constellations, also benefit from SDS to enable beam steering and bandwidth allocation so

Figure 1: Software-defined communications satellite orders and revenue, worldwide, 2022–2032



Source: NSR, an Analysys Mason company

as to be able to focus on population centers and aeronautical and maritime users, as they circumnavigate the earth.

NSR, an Analysys Mason company, projects that in the ten years to 2032 over 23,000 SDS will be built, stating that "manufacturers note that almost all requests for proposals cite software defined capabilities as a requirement. As a result, NSR forecasts that over 89% of all communications satellites built in the next ten years will feature at least some level of software- defined flexibility.

There have always been special events, the Olympics for example, that call for a temporary concentration of bandwidth in a particular location, these were known and could be planned for, months, if not years in advance. We're now living in a world, where largely due to either political unrest or increasing numbers of natural disasters, the need to focus on a particular location can arise very suddenly, and end just as abruptly. Equally, we're living in a world of high user expectations. Customers expect instant access to bandwidth-on-demand, no matter where they are. Steerable beam from SDS make this a possibility for all mobile users, whether on land, at sea or in the air.

Fluctuations in demand are almost impossible to respond to for a satellite with fixed-beams; but for software defined satellites (SDS) configurations can address complex connectivity scenarios. Beams can be steered to different locations and the amount of power and bandwidth allocated to each beam changed on demand. SDS give operators the ability to immediately and easily respond to these unexpected needs.

Implications for Satellite Operators and Service Providers

Software defined satellites are clearly a game changer for the industry. At a minimum, they enable operators of just one GEO, to future proof that satellite, permitting the operator to update the technology as and when required. For operators of NGSO satellites, they facilitate real-time power fluctuations, beam shaping and steering, in response to changing demand and to follow a moving target on the ocean, ground or in the air. Similarly, in the case of sudden changes of demand, whether that be driven by disasters or major geographic events, elections, major concerts or sporting events, for example, capacity can be dynamically focused on the appropriate area. And for operators and service providers pursuing a multi-orbit strategy, SDS becomes a basic necessity. All the more so, if they do not own all the satellites, but have partnered or collaborated with other operators in order to pursue a multi-orbit strategy, something that is occurring with increasing frequency.

Having the capability to provide multi-orbit service, is becoming a necessity for all sectors of the industry, as demonstrated by several recent announcements. SDS depend on a software- defined ground system in order to be viable. The need for a software defined ground system, therefor grows in tandem with the growth of multi-orbit systems, as the latter cannot exist without the former. One such case is from the Australian Department of Defense, which earlier this month canceled a multi-billion dollar contract with Lockheed Martin. The contract was for a GEO communications system, to deliver Australia's first sovereign-controlled satellite communication system over the Indo-Pacific Ocean region. According to a statement from the government, citing the need for a flexible solution Defense stated the decision to cancel was based on "the acceleration in space technologies and evolving threats in space since the project's commencement, Defence has assessed that a single orbit GEO-based satellite communications system would not meet strategic priorities." It then went on to state that Australia would prioritize a multi-orbit capability to increase resilience for the Australian Defence Force. Being virtualized, oftware-defined ground systems, facilitate a smaller physical footprint on the ground. For the military in particular this is a huge advantage. No longer do ground personnel need to transport hundreds or thousands of pounds of equipment between locations. Modems, switches, channelizers etc. can all be virtualized. A digital ground when combined with SDS provide unheard of flexibility and scalability for Military Satellite Communications (MILSATCOM).

On the commercial side, Intelsat, operator of GEO satellites, which (pending commercial and regulatory approvals) is planning to merge with SES, owner of O3b and O3b mPower, two MEO constellations, has an agreement with Eutelsat to use its OneWeb (LEO) constellation and also has an agreement to use Starlink (another LEO constellation). A true multi-orbit strategy. Many other GEO operators are also forging agreements and partnerships with NGSO operators.

Collaboration with the satellite manufacturer is also important as pointed out by SES CTO Milton Torres. SES have just taken delivery of the 7th and 8th O3b mPOWER satellites, from Boeing. In common with the rest of the O3b mPOWER fleet, these are fully SDS. Stressing the close collaboration between SES and Boeing since the start of the program, he commented: "With the ability to generate over 5,000 fully steerable beams, the satellites offer unparalleled flexibility, allowing SES to dynamically allocate bandwidth and power to specific regions or customers as needed. This means users can have fast, reliable internet whether they are on land, at sea, or in the air, enabling seamless connectivity for applications like video streaming, remote work, and critical enterprise operations." These are just three examples, there are many more.

Ground Networks in a Software-Defined Satellite Era: Key Requirements

by Jo de Loor

We are witnessing a major transformation driven by the integration of software-defined satellites (SDS) with virtualized, scalable, and orchestrated ground networks, where flexibility in space meets flexibility on the ground. The combination of these technologies marks a fundamental shift, enabling satellite operators to deliver services with flexibility, responsiveness, and greater efficiency. As SDS are being launched, ground network architectures are rapidly evolving to support the increased adaptability and sophistication that SDS promises, prioritizing three key elements:

A Flexible and Scalable Ground Platform

It's essential to have a ground platform that is both flexible and scalable to meet the needs of software-defined satellites. These satellites offer tremendous flexibility, serving anywhere from 50 to 500 spot beams. Therefore, the solution must not only scale in the number of spot beams and carriers, but also in gigahertz and gigabits, ensuring satellite operators and service providers can serve their customers in the most effective way.

Tailored Bandwidth Management

As these systems become more complex and challenging to manage, there will be a growing need for better resource or bandwidth management tools that can be tailored to the required go-to-market strategy. As such, providers must enable customers down the value chain to facilitate end-user services while simultaneously providing them with the flexibility to tailor to add additional value. More options are also required to address needs along the value chain, allowing for virtual network operators or resellers to define services more flexibly, including the delivery of wholesale bandwidth, enabling them to create their own services.

Optimizing Resources

The third element focuses on optimizing resources in both space and on the ground. Resource orchestration becomes a key component here. By implementing a resource orchestration solution, operators can align space resources with those of the ground segment, tailoring services to meet exact customer demands. This combination allows operators to maximize addressable markets, whether in fixed or mobility services, enhance sellable capacity, and strengthen their business case.

The Role of Intuition

The rise of software-defined satellites and multi-orbit operations has created demand for ground-segment networks that excel in scalability, cost-efficiency, and rapid deployment.

With the introduction of our Intuition ground system, satellite operators and service providers can easily scale services to maximize the value of their satellite investments.

Intuition is oriented around five capabilities: virtualization to support fast, cost-effective scaling of services; multi-orbit support to deliver services for a variety of satcom applications, regardless of orbit; standards-based network convergence to integrate satellite networks seamlessly into the global communications domain; end-to-end orchestration to dynamically adjust resource and service allocation in response to variable demand; and flexible go-to-market strategies to reach more customers with the widest possible range of business models.

As it relates to harnessing that flexibility from SDS on the ground, Intuition's innovation around virtualization and orchestration plays a key role. With its cloud-native architecture, Intuition enables faster deployments on a larger scale across more locations, with the flexibility to adapt to market needs.

Virtualized Hub Deployment Models

Since the exact number of spot beams and carriers needed is often unknown upfront, virtualization of our network and hub baseband processing facilitates on-the-fly configuration in tandem with resource management. That's where Intuition's architecture allows for various deployment models, including private cloud, public cloud and hybrid models. A hybrid cloud environment often makes sense, utilizing a private cloud for regular operations while employing public cloud services for occasional needs or disaster recovery scenarios where cost is a lesser concern.

Where total cost of ownership (TCO) is a concern, there is also an additional deployment consideration: high density, purpose built modular hub appliances, the Intuition

XBB. The highly compact and modular hub baseband can be deployed in the private cloud or within DBR, the on-prem hub infrastructure, providing maximum flexibility and scalability for various on-prem deployment architectures.

With access to multiple deployment solutions, satellite operators and service providers have the freedom to balance the need for flexibility and scalability with TCO.

Flexible Resource Orchestration

Automation and resource orchestration are essential for managing SDS complexities, enabling streamlined network management and real-time adjustments across multi-orbit environments. With tools at their hand for payload configuration management, dynamic resource management, gateway switching and seamless service transition, operators can manage their satellite resources across a load-balanced network, demonstrating flexibility and effectiveness across space and ground segments. Resource orchestration can be broken down into two main types: static and dynamic strategies. Static strategies, like beam mapping and bandwidth reconfiguration, help optimize system capacity by adjusting to shifts in demand and managing bandwidth resources more efficiently. Dynamic strategies, on the other hand, come into play when real-time adjustments are needed—such as enabling a "follow me" feature for moving vessels, activating beams on demand, or seamlessly handing off connections between satellites. With Resource Orchestration APIs Intuition enables operators to autonomously adapt resource assignments in near real-time and apply mitigation strategies to help alleviate congestion by reallocating terminals and resources across beams and satellites, working to bridge the gaps between the space and ground segments.

Unlocking the Full Potential of SDS

Looking ahead, the transition to a virtualized cloud-native architecture with orchestration positions software-defined satellites for future success.

By focusing on flexible cloud deployment scenarios, advanced management tools, and resource orchestration, satellite operators have the best tools with Intuition to unlock the potential of Software-defined Satellites with new levels of performance and service delivery.

For a deeper dive into resource orchestration read our **joint whitepaper with Calian here**.

Jo de Loor is the Vice-President for Market Development and Strategy at ST Engineering iDirect.

Given the close interdependence between SDS and a software-defined ground, satellite operators, generally agree that from the onset, the planning of the ground systems should be fully integrated with the planning of the satellite. To quote Kanaka Hidayat, Technical advisor for BAKTI, operator of the Satria-3 Indonesian satellite: "The ground systems has to be part of the equation from the beginning. The satellite and the ground systems need to work very closely in order to come up with an integrated system that meets the client's requirements. Working together from the beginning will ensure that there will be no integration problems during the process which can be costly in terms of time and budget." Hidayat has been involved in the planning of several satellites for various operators and has seen the pitfalls of planning for the satellite first and the ground system coming later.

Given the rapid changes occurring on both the supply and demand side, total flexibility is the key to future success. This means a fully software-defined system, encompassing both the satellite and ground system. This will give operators and service providers, the confidence that their systems are future-proof.

"...A fully software defined system is the key to the future. The software defined ground system needs to be fully integrated with the design of the satellite from the outset. By aligning the ground network capabilities with the dynamic nature of SDS, operators and vendors can unlock new business opportunities, enhance service agility, and better meet the evolving demands of the market..."

Ground Systems

Satellites are only as good as the ground system controlling them. This is particularly true for SDS, the traditional static infrastructure simply cannot support dynamic nature of these satellites. It is essential that the ground system is as dynamic, agile and flexible as the satellites it is controlling. In order to provide this versatile and dynamic response, five key elements need to be prioritized.

1. Resource orchestration is the first, and arguably the most importtant element. This means optimizing resources both in space and on the ground. The tight orchestration of beams, power and frequency allocation that can only be achieved with resource orchestration from a software defined ground system, gives the operator the ability to optimize capacity utilization, across multiple satellites and orbits, leading to maximum sellable capacity and increased revenues.

This dynamic approach to operations, offers several benefits for both operators and users. Network reconfiguration, for example allows operators to quickly react to changing user traffic patterns, whether caused by business growth, world events, technology improvement or the addition or subtraction of satellites in the bandwidth pool for example.

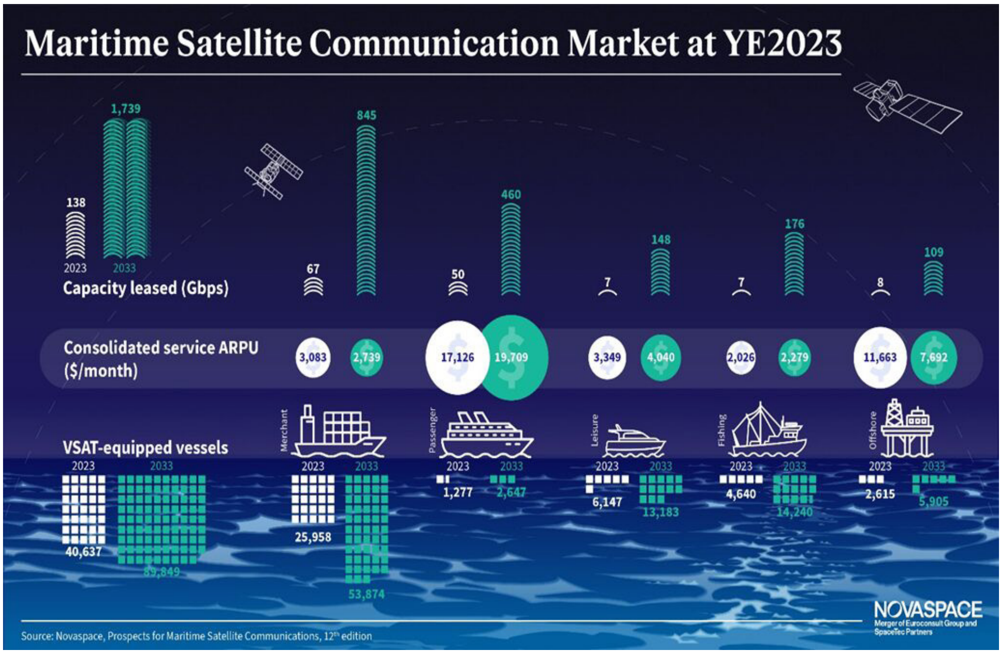
Similarly, orchestration provides a rapid and automatic response in the event of failure or weather events impacting part of the communications chain. Automatic prioritization of network traffic, provides the service provider with a robust network, maximizing revenue as service restoration prioritizes committed SLAs and CIRs, and the most profitable customers.

2. The ground platform needs to be both flexible and scalable, ta-king into account that not all software defined satellites are identical. For example, a SDS could be a GEO, MEO. LEO or HEO, and could have anywhere between 50 to 500 spot beams. This means that the controlling ground system must be able to scale not only in the number of beams and carriers, but also in GHz and GBs in order to give operators and resellers the flexibility to serve multiple customers in different ways.

3. The ground system needs to be optimized to meet the needs of customers along the entire value chain, particularly, as more and more operators and service providers turn to a managed service offering. Essentially, customers, whether these be service providers, resellers or virtual network operators, need to be offered a virtual "tool-box" from which they can design the services they want to offer. For example, they may want to pool bandwidth from multiple satellites and orbits in order to create a package of bandwidth or services targeted to a particular country, region or customer.

4. Virtualization or cloudification is also an important element of a flexible ground system. Virtualized ground networks enable the abstraction of the software functions from the hardware and enable these to be moved to the cloud, using commercial-of-the shelf (CoTS) parts. This allows for automated scaling and more efficient resource management. Decoupling many functions that were embedded in the hardware and making them cloud-native, not only allows users to control systems from anywhere, it also changes the investment in the ground infrastructure from primarily being capital expenditure (Capex) to an operating expense (Opex). So making it easier for users to implement new services as needed and upgrade in a smooth linear

manner as demand increases.



5. It is also important that the ground system interfaces adhere to open standards, compatible with those used in telecom. Historically, the satellite industry has been isolationist, relying on proprietary standards that not only resulted in the telecom industry regarding satellite as the technology of last resort, but also made it difficult for different satellite industry players to work together as each had their own technology and standard. To some extent this has benefitted ground service providers, as proprietary, hardware-based standards, made it easy to lock-in customers, as changing providers meant major capital expenditure.

It has now become clear, that proprietary standards no longer serve the industry.

Maritime Use Case

Integrating resource orchestration with the software defined ground segment system, is key for most applications, but none more so than for mobility. Taking maritime as an example, this integration, permits satellite operators to provide flexible, dynamic and efficient solutions, as vessels move around the oceans and bandwidth needs change.

The martime market is one of the fastest growing segments of the satellite industry. As can be seen from the graph from Novaspace, the martime sector will be requiring more than a tenfold

increase in capacity in the next decade. Orchestration gives the ability to control and reconfigure

satellite resources in real time. Couple this with the ground system's capacity to manage and

monitor these resources, continuous, high-quality service can be provided for vessels at sea. The

main elements of this combined system are:

1. **Dynamic Beam Reconfiguration.** Satellite beams are adjusted in real-time to track vessel movement. Resource orchestration interfaces with the ground system to adjust the payload configuration, to ensure that beams follow the vessel, so providing continuous, uninterrupted service, without the need for fixed pre-allocated beams.

2. **Efficient and Customized Coverage**. The combined system enables efficient coverage by dynamically allocating smaller, targeted beams where and when needed. As the dynamic focused beams follow vessels, bandwidth and power are adjusted to meet traffic demands and to maximize coverage efficiency, to make optimal use of the satellite capacity. By controlling the satellite's payload dynamically, resource orchestration can adjust beam shapes, sizes, and power levels based on the specific needs of maritime routes, busy ports, or high-traffic zones.

3. **Real-time Adaptability and Flexible Bandwidth Allocation.** A key benefit of integrating resource orchestration with the ground system is real-time adaptability. The system can continuously monitor vessel movements, traffic patterns, and environmental factors (such as weather or interference), making on-the-fly adjustments reallocating traffic, adjusting transmission parameters and reshaping beams to ensure seamless service. The ground system also provides flexible bandwidth in real-time to meet varying maritime needs. If a vessel's operational or passenger load changes, the ground system can reassign bandwidth resources, scaling up or down as needed, ensuring that fluctuating traffic demands are met without service degradation.

4. Enhanced Tracking Capabilities. For vessels traveling through narrow waterways or along specific routes, beam hopping facilitated by resource orchestration ensures continuous coverage. The ground segment system works with resourceorchestration to optimize the management of satellite beams along these paths. As ships "hop" from one beam to another, the orchestration system manages the transition between beams, ensur-

ing seamless connectivity in challenging geographical environments. The ground system ensures that the necessary resources are available for beam switching and tracking, minimizing the risk of service interruption.

5. **Improved Resource Efficiency.** The combined ground system and resource orchestration ensure optimal network efficiency. They continuously monitor satellite resource usage and adjusts allocations based on real-time demand. If certain beams or frequencies are underutilized, they can reallocate them to higher-demand areas, ensuring that all available satellite resources are used effectively. This capability not only improves the overall efficiency of the satellite network but also allows for faster responses to changing user requirements, reducing waste and improving overall service quality.

These dynamic results can occur as a result of a tight integration of resource orchestration coupled with a efficient ground system and a dynamic payload from the space segment.

Recommendations

The satellite industry is changing very rapidly. SDS are replacing traditional satellites with fixed payloads and capabilities, but will coexist with them for at least the next few years.

In order to navigate these changes, satellite operators and service providers need to look for new capabilities in their ground segment partners.

• Ideally, the ground service partner, needs to be involved and work with the satellite manufacturer from the very beginning, so that the virtual ground segment will be fully integrated with the software defined satellites from the outset.

• Operators, manufacturers and ground system providers should choose open standards and interoperable systems, in order to facilitate seamless integration across different satellite networks and ground platforms, including easy interconnection with 5G and other telecom networks.

> ***"...These dynamic results can occur as a result of a tight integration of the resource orchestration coupled with a efficient ground system and a dynamic payload from the space segment..."***

Ground systems that adopt a Cloud-Native Architecture, in order to facilitate the use of public and private cloud resources will be invaluable to those customers whose requirements fit a Cloud environment. However, there will likely be other scenarios, at least in the short-term, where other deployments make sense, so providing a range of options in the ground system is the best solution.

• The ground system vendor should offer End-to-End orchestration, that extends from the satellite payload to the user terminal.

• Cybersecurity must be a key feature. Vendors should implement advanced encryption, authentication and anomaly detection in order to ensure the integrity and resilience of the network.

• Most importantly, the ground segment provider needs to be able to seamlessly handle, traditional wide beam satellites, high-throughput satellites (HTS), multi-orbit systems, and SDS, so ensuring a smooth growth path for satellite service providers and resellers.

Conclusion

A fully software defined system is the key to the future. The software defined ground system needs to be fully integrated with the design of the satellite from the outset. By aligning the ground network capabilities with the dynamic nature of SDS, operators and vendors can unlock new business opportunities, enhance service agility, and better meet the evolving demands of the market.

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