Brief: Downlink Bandwidth Constraints and Solutions

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Findings

Rotoiti interviewed several individuals who have expertise in satellite communications. Based on those conversations, this brief summarizes downlink bandwidth constraints and solutions.

Downlink Bandwidth Constraints

Ground station companies offer limited downlink throughput. After collecting data, satellites downlink it to Earth. To downlink, satellites must be within range of ground stations. Ground stations have limited downlink "throughput", meaning the amount of data they can receive. Since ground stations cannot receive all data from all satellites, they prioritize downlinking from certain satellites. There is more demand than supply, in other words, for downlink throughput.

- Demand for a ground station's downlinking depends on many factors. One factor is geography; some ground stations, particularly those close to the poles, are more in demand as they lie in the path of many satellites' orbits. Another factor is connectivity to ground-based communications networks, since data must be transmitted from ground stations to downstream data users. This usually happens via fiberoptic cables.

Related to throughput constraints, downlinking often faces high latency. Downlink throughput constraints mean satellites must often wait for hours or days before downlinking data. Satellites may pass over ground stations that could potentially downlink their data, but because those ground stations are already busy downlinking for prioritized customers, the satellites must wait to come within range of other ground stations. High latency, meaning downlinking delays, is a common problem. Other issues exacerbate latency besides throughput constraints. Satellite owners and operators may, for instance, only be allowed to downlink to ground stations in certain jurisdictions, or they may only have contracts with certain ground station companies.

- Different satellites and ground stations use different bands of the radiofrequency spectrum. Different bands have different characteristics, such as allowing more throughput or requiring more power. Some bands are more popular, restricted, or technologically developed than others. The extent that throughput and latency issues affect satellite owners and operators is informed by which band they use. Software-defined radio permits some flexibility, allowing transceivers to use various bands.

- Uplinking, which is usually required in order to task satellites, also sometimes faces latency constraints. It may take some time, in other words, for a satellite to receive taskings from a ground station. Uplinking is less affected by throughput constraints, however, because uplinking typically entails sending less data than downlinking.

Bandwidth issues limit the potential value of satellite-collected data. Since there are constraints on how much data can be downlinked, satellite owners and operators must be selective when deciding what data to collect and sell to downstream data users. Satellite

owners and operators cannot task their satellites to meet the data needs of all downstream data users. Ultimately, downlink bandwidth constraints hinder downstream data users' access to data. This stifles their innovation and creation of products based on satellite-collected data.

Bandwidth issues especially affect ground station companies' low-tier customers. Ground station companies prioritize satellite owners and operators that pay more in order to be guaranteed more throughput, usually measured in terms of the number of "passes" over ground stations. Low-tier customers, for instance, may be guaranteed only two passes per day, whereas high-tier customers may be guaranteed dozens of passes. Contract arrangements directly affect satellite owners and operators, and indirectly affect downstream data users.

- Business relationships influence the effects of ground station contract arrangements. Satellite owners and operators with few guaranteed passes, for instance, will likely task satellites to prioritize the needs of data users with whom they have closer partnerships.

- The ground station business is dominated by a few large firms. A reason for this is high barriers to entry, because building ground station networks requires significant capital and subject matter expertise. Such a concentrated market structure typically gives suppliers (such as ground station companies) more leverage in contract negotiations.

Bandwidth issues particularly hinder downstream data users who are attempting to develop low-latency products. The more important that low latency is for a product, the more of a difficulty bandwidth issues pose. For scientists trying to understand how tectonic plates move over the millennia, for example, it is of little concern if data is a week or two old. For disaster management organizations trying to deploy personnel to prevent a genocide, on the other hand, it is important to have near-real-time monitoring capabilities. For many firms, current downlinking arrangements are a serious constraint in terms of developing low-latency products.

- If more near-real-time products can be developed, this would likely transform the space industry. Products providing near-real-time monitoring and analysis would likely be very marketable and attract significant investment. It is debatable, though, if satellites will ever outcompete drones or planes in terms of providing near-real-time monitoring.

Possible Solutions to Downlink Bandwidth Constraints

One solution to address bandwidth constraints is building more ground stations. This solution directly tackles throughput – collectively, more ground stations can downlink more data. Indirectly, this would also likely ameliorate latency, since with more ground stations, satellites would likely have more frequent downlink opportunities. One difficulty with this solution is building ground stations is risky since it requires significant up-front capital investment. If downlink demand projections are incorrect, then companies building ground stations will fail to recoup their investments. Demand for ground stations will be affected by the advent of other solutions like those discussed below (e.g. intersatellite communications or onboard computing).

- There is a push towards using higher frequency bands since they allow for more throughput. These higher bands, however, experience path loss when the signal loses power density as it propagates. They thus often require more power to boost the signal.

Another solution to address bandwidth issues is creating relay networks of satellites. Several companies are developing such networks in order to indirectly relay communications between satellites and ground stations. This solution targets latency rather than throughput. With relay networks, a satellite would not need to be within range of a ground station in order to downlink; it could instead transmit data via the network to another satellite that is within range of a ground station, and then that other satellite could downlink the data. Such relay networks would obviate the need to wait for certain satellites to be over certain ground stations.

- Some planned networks include satellites in low-Earth orbit (LEO) and geostationary orbit (GEO), and others include only LEO satellites. Each model has different advantages. With the LEO/GEO model, fewer satellites are needed, because GEO satellites can "see" more ground stations on Earth. Sending data from LEO to GEO and back to Earth, however, takes time and thus has latency issues. A LEO-only network, on the other hand, requires more satellites to enable global coverage, but has lower latency.

Another solution to address bandwidth issues is onboard computing. Onboard computing allows satellites to intelligently make decisions in orbit without human input. It can help satellites decide where to focus data-collection efforts. Onboard computing can also help satellites after they have collected data to decide what data is useless and does not need to be downlinked, deleting it rather than sending it to a ground station. Onboard computing can also process data to make it more useful for downstream users, and in doing so, reduce the amount of data to downlink. All of these computing services mean that satellites can downlink less, more useful data, thereby reducing the obstacles posed by throughput or latency issues.

- A combination of onboard computing and relay networks can even better address bandwidth issues. If satellites are networked with each other, this can allow some satellites to specialize in data collection, others in onboard computing, and others in relaying and downlinking data. Satellites can also fly in formation, with a lead satellite's onboard computer, for instance, telling other satellites where to focus data collection.

An emerging technology that may address bandwidth constraints is optical communications. Besides using radiofrequency signals for communication, satellites and ground stations can use optical signals – lasers that transmit data. Optical communications are more targeted, and are thus harder to jam and intercept. There are associated difficulties, however. The atmosphere can easily disrupt optical signals, it is necessary to be precise when "pointing" optical signals, and the technology's novelty means it may be more expensive to build optical ground stations compared to traditional ones. For these reasons, it may make more sense to use optical communications for intersatellite networking, rather than for downlinking to ground stations.