Satellite-to-cellular services, now and into the future

A TECHNICAL AND REGULATORY OVERVIEW

DLA PIPER

Introduction

The telecommunications industry has seen significant growth in new and innovative technologies that expand service options and availability for consumers. Among these advances has been the convergence of satellite and cellular technologies. Satellite-to-cellular, or sat-to-cell, technology enables terrestrial cellular service to overcome some coverage limitations, including restrictions on tower placement, land use restrictions (ie, in the National Parks), and the topography of certain areas. Sat-to-cell allows wireless coverage to extend into areas that are too difficult to serve utilizing only cellular technology (due to geography, lack of power, lack of available fiber).

Several companies have worked to develop sat-to-cell into a viable service and are now being followed into the space by major providers and equipment manufacturers. In this handbook, we provide an overview of current sat-to-cell initiatives, as well as the engineering and regulatory issues implicated by this nascent service. With increasing deployments and partnerships to provide sat-to-cell, we expect the service will be a major focus for regulators in 2023 and beyond.

Current initiatives

In August 2022, a partnership was announced that would allow for sat-to-cell operations. In September 2022, a new initiative was announced for a sat-to-cell service that allows users out of range of terrestrial network coverage to contact emergency services. It officially launched in November in the United States and Canada. Also in September 2022, a new satellite successfully launched that aims to provide a cellular broadband network accessible directly by standard mobile phones via a low Earth orbit satellite network. At around the same time, another entity received authorization from the FCC to launch commercial services for its global constellation of non-geostationary orbit (NGSO) satellites in low Earth orbit (LEO) to provide two-way satellite connectivity for existing devices currently operating on terrestrial cellular networks.

Engineering issues

When seeking to implement a sat-to-cell service, myriad engineering and technical issues must be overcome.

Because satellite systems are located great distances from receivers, ensuring that the communications make it to consumers is extremely challenging. This issue is managed by carefully considering the system's "link budget" (an accounting of all of the power gains and losses that a communication signal experiences).

In addition, latency (or the time it takes the signal to travel through the network) is another significant technical obstacle. Ensuring that the mobile device is able to receive and decode the satellite signal must also be considered.

Finally, interference issues between the satellite and terrestrial cellular systems must be modeled and analyzed to ensure seamless coexistence. Each of these issues is addressed in detail below.

A. Link budget

A primary engineering challenge for satellite-to-cellular is overcoming the link losses due to the vast distance between the satellite and the user equipment.

One entity has reported successful completion of two-way communications between its satellites and handheld devices, noting the "uplink challenge" that exists between the low power handheld and the distant satellite base station. The satellites envisioned to provide this service are 500 to 1,500 km away at zenith and even further when not directly overhead.

To quickly illustrate this challenge, consider the free space path loss between a terrestrial base station and user equipment (UE) separated by five kilometers versus that of a satellite at 1,500 kilometers. Path loss is the inverse of the wavelength squared multiplied by the spreading loss which is function of the distance squared. In other words, for a UE operating at 2 GHz and 5 km away from the base station, the free space loss will be:

$$FSPL = 10 \log \left[\left(\frac{4\pi d}{\lambda} \right)^2 \right] = 10 \log \left[\left(\frac{4\pi d * 5{,}000}{0.15} \right)^2 \right] = 112.4\ dB$$

And in the case of the satellite at 1,500 km away, the path loss becomes 162 dB – nearly 50 dB of additional path loss to communicate with the same UE hardware. Combine this path loss with the satellite antenna gain and noise temperature and the transmit EIRP of the handheld, and the challenge becomes more apparent.

Assume the carrier bandwidth is 5 MHz, the transmit EIRP is 0 dBW, the satellite receive antenna gain is 19 dBi, and noise temperature is 400 Kelvin. Then, the signal-to-noise ratio (SNR) for this link is found (in log scale) by:

$$SNR = Pt - FSPL + Gr - (k + T + B)$$

which results in an SNR of —7.4 dB. Since this link does not close, and the power of the UE is limited, the link bandwidth needs to drop to a few hundred kilohertz so that the link can close with margin. The link bandwidth would further decrease if the UE is not at the satellite antenna peak gain, or directly overhead.

The link needs a narrow bandwidth to close with positive link margin. These links will be on the order of several hundred kilohertz as mentioned above. If the link uses BPSK or π/2-BPSK (for better peak to average power ratio), the channel capacity at best is one bit per second per hertz which yields a channel capacity of 160 kbps if the channel bandwidth was 200 kHz with a 20 percent roll-off. Under ideal circumstances, these return links are low-data rate and could only support voice and texting at level of quality on the order of 2G capability.

B. Latency issues

One of the more intuitive challenges with satellite-to-cellular communication is the delay attributed to the distance between the satellite and the UE. Latency can create havoc for certain access technologies and can diminish the user experience for certain applications.

The typical round-trip time from the gateway earth station to a satellite at 1,000 km back down to the UE is around seven milliseconds. This is only half of the circuit, however, meaning the total time for a handshake with the UE from the satellite is around 14 milliseconds. Additionally, this calculation accounts only for the air interface latency – network latency would cause further delay. Compare that with the path latency of a terrestrial link of five kilometers between the base station and UE, which would be 30 microseconds – 200 times faster than the satellite link. If all other parameters of the networks are the same, the satellite link is 200 times slower than the terrestrial link.

Access technologies like TDD for multiplexing users in the same frequency may need to be adjusted to handle the significant delay along the path. There are other multiplexing schemes like FDD, but the MSS has limited spectrum available to divide among its users.

Nevertheless, the latency may prove too much for TDD to effectively work, particularly when the distances between the UE and satellite vary by tens to hundreds of kilometers. The algorithm would need to adapt to the guard time in between transmission and reception windows based on the changing path length without timing out. These hurdles may be why FDD appears to be the focus for satellite-based NTN despite the limited spectrum available to these MSS frequencies. The carriers appear to be operating with a 360 kHz bandwidth inside an overall system bandwidth of 30 MHz at S-band.

Finally, highly tactile applications like vehicular communications, robotics, and virtual or augmented reality can be rendered inert by high latency. These applications operate best when end-to-end latency is one millisecond or less. Under the present circumstance, satellite-to-cellular links are limited by their capacity which would also not support these time-sensitive and high-bandwidth applications. However, even if bandwidth increases such that capacity is not an issue, these applications would still be impacted by the air interface latency.

C. Device issues

Mobile phones already have multiple antennas onboard for cellular, Wi-Fi, near-field communication, and GPS communications. These antennas require space to ensure that they successfully cooperate without having destructive interference created among them.

In addition to polarization discrimination as a means to avoid interference, device manufacturers are looking to beamforming techniques and multi-input-multi-output (MIMO) antennas as necessities on new smart phones capable of 5G and future generation mobile broadband communications. Beamforming uses an array of antennas to electronically form and steer the antenna beam in the direction of the base station. MIMO antennas similarly have multiple antennas that effectively create different channels between the transmitter and receiver that can be power combined as a means to improve signal quality.

One area of possible design change for mobile devices in support of satellite-to-cellular communications is implementing cellular antennas that are capable of beamforming. Low-band cellular antennas today are typically omni-directional, using simple antennas which do not offer high antenna gains. The ability to electronically form and steer a high-gain antenna beam in the direction of the satellite could greatly improve the link performance. This, however, comes with additional cost, power requirements, and complexity which would need outweighed by the operational benefits provided to the end user.

In 3GPP's Release 16, the technical report 38.821 addresses solutions for new radio to support non-terrestrial networks (NTN) which includes communications with satellites. In this standard, UE having omni-directional antennas and directional antennas are considered. However, the directional antennas operate up to a size of 60 cm and with an available power of 20 W which are not handheld devices. For handheld devices operating at S-band frequencies (ie, 2 GHz), the technical report assumed an omni- directional antenna and a peak transmit EIRP of 23 dBm. A possible next step to advance the adoption of beamforming antennas on handhelds for the satellite communications could include a modification of this technical report.

D. Interference issues

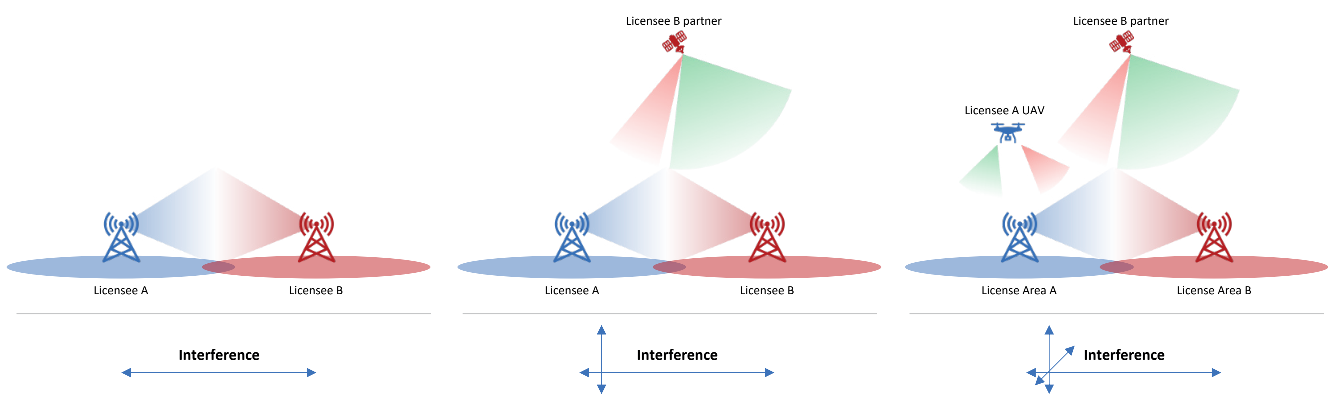
Terrestrial mobile network operators have built and deployed their systems on the backbone of spectrum acquired through competitive auctions. In some cases, billions of dollars have been invested to secure spectrum for current and future mobile networks.

A significant component of this investment was a high degree of certainty about the interference environment now and into the future. Introducing a new dimension of interference will require careful consideration.

The illustration below demonstrates the potential evolution of the interference environment relative to the expectations at the time of auction.

As the scenarios move from left to right, the progression of interference sources increases – all of which are being contemplated by 3GPP for the system of systems into which 5G is currently evolving.

While the technology will advance in multiple dimensions, the regulatory certainty that was foundational to that first spectrum investment needs to be secured or at the very least developed in a manner that does not undermine its long-term integrity.



Regulatory issues

A. Spectrum allocation

By definition, satellite systems can provide service to mobile earth stations from space stations and between space stations and may even include feeder links necessary for operations. Satellite operators have historically used the mobile satellite service (MSS) to provide narrowband connectivity to mobile users via specific, purpose-built handsets.

A benefit of these services is that users can be connected anywhere on the globe with a clear view of the sky, which is otherwise impossible with terrestrial networks. However, these applications are limited in their bandwidth and throughput, and the single-use hardware needed to facilitate these services only connects to the MSS network.

One of the most important regulatory questions for sat-to-cell service is whether there is a need to formally introduce new MSS allocations or continue authorizations on a non-conforming basis with commercial arrangements managing interference. Any satellite that seeks authority to transmit and receive in licensed mobile terrestrial spectrum is a non-conforming use inconsistent with the Table of Frequency Allocations. The value of introducing new MSS allocations is that this sat-to-cell application would pair the use case with the radio service allocation. Moreover, a new allocation, if made, would be supported by thorough studies and regulatory considerations necessary to solicit input from a wide range of stakeholders, including the incumbent services. On the other hand, a new MSS allocation in licensed mobile spectrum bands may undermine the operational certainty of incumbent mobile network operators that acquired their spectrum through competitive auctions. The new MSS allocation would need to ensure the current and future mobile applications could grow without interference concerns.

Alternatively, authority to operate satellite services to mobile frequencies can be handled on a case-by-case basis through waivers of the Table of Frequency Allocations – effectively operating the satellite networks under No. 4.4 of the Radio Regulations. As discussed in more detail later, No. 4.4 is a provision by which administrations may notify the use of a frequency for a radio service that is not allocated to that frequency. This approach would allow satellite operators to individually present justification for waiver and interested stakeholders to provide their input through the public comment process.

The benefit of this approach is that the explicit and narrow scope of a single application can be evaluated and conditioned based on the facts and merits of the proposed service with respect to existing users of the spectrum – there is no need to boil the ocean. The downside would be establishing precedent that others may follow, potentially proliferating a radio application that is non-conforming and resulting in unforeseen harm to incumbent services and their consumers. Such an approach also increases the number of non-conforming frequency assignments notified to the ITU, which is generally disfavored because non-conforming assignments have no technical boundaries other than "non-interference basis."

B. Sharing/interference considerations

As already noted, there is a potential for significant interference issues that must be resolved through hard protection limits or coordination. Under traditional spectrum sharing models for terrestrial services, two systems are separated in geography, allowing the same spectrum to be used at the same time. For MSS systems, two or more systems generally use frequency segmentation so that they may operate at the same time over the same area. Band segmentation is necessary since the UEs typically have non-directional antennas that are unable to reject the interference from another satellite that may be visible to the UE.

Having an MSS system share the same frequencies but avoid certain geographies is possible, but the fidelity by which the satellite can avoid geographies is at a scale much larger than perhaps required by co-frequency terrestrial networks. This is illustrated in the figure below.

This figure shows a 100-kilometer radius (red) as a hypothetical MSS coverage beam and a 4.5-kilometer radius (cyan) as a hypothetical mobile network cell coverage area. To augment the coverage of the terrestrial network is not a challenge. The difficulty is augmenting coverage in a precise fashion that does not interfere with other, nearby terrestrial networks using the same spectrum.

C. International considerations

Under Article 9 of the Radio Regulations, MSS satellite networks trigger coordination under No. 9.11A, which relies on bandwidth overlap according to Table 5-1 of Appendix 5 to the Radio Regulations.

Simply put, any two MSS frequency assignments that have overlapping bandwidth require coordination. As noted above, these MSS networks and their associated mobile earth stations, operate large satellite beam footprints and omni or near-omni directional antennas that make it difficult to share the same spectrum at the same time over the same geography. Accordingly, band segmentation or variations of it is routinely employed by MSS operators that wish to serve the same geography. Alternatively, operators that have different geographic service objectives can both use the same spectrum provided the service areas are sufficiently separated in distance to avoid interference between the two systems.

The Radio Regulations also contemplate governmental administrations seeking to use a particular frequency assignment for a radio service that is specifically allocated for that service under provision No. 4.4. This provision generally restricts the use of a frequency to the radio services allocated to that frequency but exceptionally permits use by other radio services provided these other services accept harmful interference and not create harmful interference.

Apart from the default obligation to eliminate harmful interference, the Radio Regulations Board, a 12-member elected body within the ITU that handles potentially ambiguous regulatory matters, clarified through a Rule of Procedure that administrations seeking to use No. 4.4 shall first determine that no harmful interference will occur into conforming services and shall determine what measures are needed to immediately eliminate the interference.

Administrations and their satellite operators that seek to use terrestrial mobile allocations where there is no MSS allocation will need to determine how they can ensure the protection of incumbent radio services, particularly the terrestrial services they seek to augment. For example, satellite transmissions would need to respect a power flux-density on the Earth to ensure mobile base stations are protected. In the uplink, transmissions from the handheld device must ensure their emissions do not create harmful interference on the ground or into space. In both cases, there are no international provisions or standards that contain limits previously derived and agreed to ensure these protections. The protections afforded to the other conforming users of the spectrum will be determined, largely unilaterally, by the operator of the non-conforming satellite network.

The international Table of Frequency Allocations includes identifications for international mobile telecommunications (IMT) in certain frequency bands. IMT is an identification within the mobile service or mobile-satellite service that provides globally and regionally harmonized technical and regulatory conditions for mobile telecommunications. The satellite component of IMT enables exclusive satellite to handheld service or coverage augmentation for terrestrial infrastructure using satellites.

In the Radio Regulations, there are several Resolutions that describe the satellite component of IMT. Resolution 212 describes the implementation of satellite and terrestrial IMT identifications in the 1980-2010 MHz and 2170-2200 MHz frequency bands. In this Resolution, it is noted that the terrestrial and satellite components of IMT are not feasible to operate co-coverage and co-frequency independently but that it could be feasible if a network manager controls both the satellite and terrestrial infrastructure. Additionally, Resolution 225 states that the frequency bands 1518-1544 MHz, 1545-1559 MHz, 1610-1626.5 MHz, 1626.5-1645.5 MHz, 1646.5-1660.5 MHz, 1668-1675 MHz and 2483.5-2500 MHz may be used for the satellite component of IMT provided that this use follows the technical and regulatory provisions of the MSS in these frequencies.

It should be noted that these Resolutions invite additional sharing and coordination studies related to the use these frequencies by the MSS for the satellite component of IMT, suggesting there is still work to be done.

The invitation for more studies notwithstanding, and recognizing the technical and regulatory disadvantages with the use of terrestrial mobile spectrum by satellite under provision No. 4.4, operators should prioritize use of these frequency bands identified for the satellite component of IMT in their satellite-to-cellular initiatives.

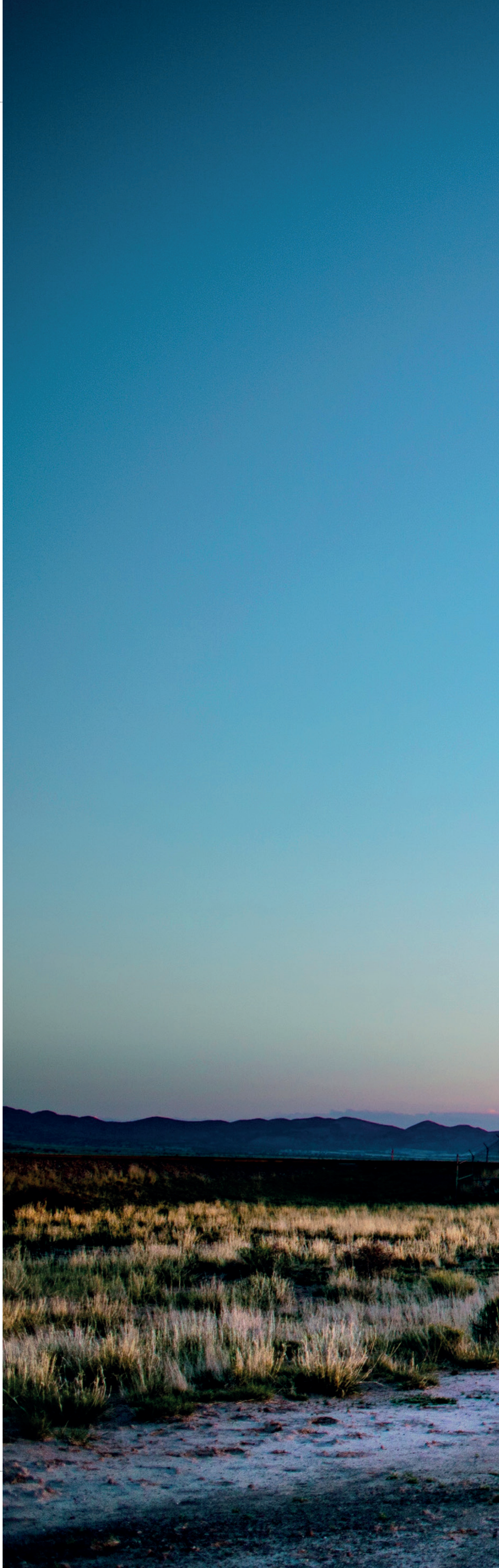
Emerging issues in 2023

Several proceedings and activities that may determine the future of widespread, commercially available sat-to-cell services warrant following in 2023. There is a petition for declaratory rulemaking pending with the FCC seeking US market access for a sat-to-cell service. This petition was largely opposed by commercial mobile providers, noting that the applicant's plan to lease terrestrial mobile spectrum was not in accord with the FCC's secondary market rules, which do not allow a lessee to use spectrum for services that are not authorized for use by the underlying licensee and would interfere with terrestrial mobile operations. There is also another application and petition for declaratory ruling filed in December 2022. The next steps or actions by the Commission on these requests bear watching.

At the same time, one of the biggest open questions is whether the FCC will initiate a proceeding to address the lack of regulatory clarity regarding sat-to-cell deployments and their ability to co-exist with terrestrial mobile spectrum licensees. Several parties have suggested that the agency examine sat-to-cell requirements in a rulemaking proceeding, rather than through the petition and waiver process.

Internationally, the issue of satellite-enabled connectivity continues to generate significant interest, as the current and previous World Radio Conference (WRC) cycle has seen focused attention on possible new MSS allocations. Leading up to WRC-19, Agenda item 9.1, Issue 1 invited administrations to study the operational and technical measures to ensure coexistence between the satellite and terrestrial components of IMT systems in the 1980-2020 MHz and 2170-2200 MHz bands.

Similarly, the current study period for WRC-23 includes Agenda item 1.18, which invites administrations to study portions of the spectrum between 1.5 and 3.5 GHz for possible new MSS allocations to support low data-rate systems. The US WRC preparatory process has preliminarily concluded that no changes are appropriate at this time based on studies performed to date. Finally, a preliminary Agenda item (2.13) for WRC-27 has been established that examines portions of the 1.5 GHz to 5 GHz frequency range for possible new MSS allocations. This series of agenda items and issues demonstrates an interest in finding additional MSS spectrum below 5 GHz, potentially in pursuit of additional capacity for sat-to-cell connectivity.



Conclusion

As this burgeoning market continues to develop, established players and new entrants alike will require significant guidance on how to address the domestic and international concerns implicated. DLA Piper's highly experienced Engineering Services team leverages the firm's global reach to provide engineering analysis combined with legal advice and advocacy that integrates technical arguments. The team's experience and capabilities have helped many companies navigate these and other novel, complex issues.

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