IFRI
STUDIES

GEOPOLITICS OF TECHNOLOGY CENTER |
SPACE PROGRAM

SEPTEMBER
2024

Sat-to-Cell
The Path to Universal Connectivity?

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ISBN: 979-10-373-1005-7

How to cite this publication:
Eric Bottlaender and Paul Wohrer, "Sat-to-Cell: The Path to Universal Connectivity?", *Ifri Studies*, Ifri, September 2024.

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Résumé

Le *Sat-to-Cell* est un nouveau type de service qui permet de connecter des smartphones directement aux satellites. Il a récemment permis de nouveaux usages tels que des SMS d'urgence par satellite. La technologie évolue rapidement et de nombreuses questions se posent désormais sur ses impacts potentiels.

L'émergence du *Sat-to-Cell* a été favorisée par l'évolution de l'industrie spatiale, en particulier les grandes constellations de satellites. Le cadre réglementaire a également progressé, avec l'implication d'organismes de standardisation pour la mise en place de ce type de services. Proche cousin technologique de l'Internet des objets (IoT), sa dynamique économique est dominée par des acteurs américains et chinois, avec un retard notable des acteurs européens. Par rapport à ce qui a le potentiel de devenir un nouveau marché, l'entreprise SpaceX apparaît particulièrement bien positionnée.

Ces nouvelles applications ne posent pas seulement des questions économiques, mais sont porteuses d'enjeux géopolitiques. Une infrastructure de connectivité globale pourrait permettre l'émergence de nouveaux types d'opérations militaires ou de *soft power*, voire signer la fin du contrôle des États sur Internet dans certains pays. Il semble aujourd'hui nécessaire d'anticiper les possibles évolutions des usages pour s'y adapter.

Le *Sat-to-Cell* reste cependant une technologie balbutiante, incapable de rivaliser à court terme avec les réseaux téléphoniques terrestres. Le marché potentiel reste incertain et comporte des risques d'interférences avec les opérateurs établis. Certaines caractéristiques poussent cependant à le considérer comme une technologie de rupture, dont il faudra surveiller l'évolution.

Executive summary

Sat-to-Cell is a new type of service that connects smartphones directly to satellites. It has recently enabled innovative applications such as emergency text messaging via satellite. The technology is developing rapidly, and many questions are now being raised about its potential impact.

The emergence of Sat-to-Cell is has been facilitated by the evolution of space technologies, in particular large satellite constellations. The regulatory framework has also evolved with the involvement of standardization bodies, which helped implement this type of service. As a close technological relative of the Internet of Things (IoT), its dynamics are dominated by American and Chinese companies, while European actors are almost absent. SpaceX appears in a particularly strong position to exploit this new market.

In addition to economic issues, geopolitical questions are also raised by these new applications. A global connectivity infrastructure could enable the emergence of new military uses, new regime destabilization operations or even the end of state control over the Internet in certain countries. It seems necessary to anticipate possible changing use cases and to adapt to them.

Sat-to-Cell is still in its infancy and cannot compete with established networks in the short term. Its accessible market remains uncertain, and there is a risk of interference with terrestrial operators. However, there are several reasons to see it as a potentially disruptive technology whose development should be monitored.

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Introduction

In March 2024, a family was rescued after being caught in a snowstorm in a forest in Oregon. Stranded with no mobile network coverage, the family was able to send an emergency SOS signal via satellite using their iPhone. This new feature, available on Apple's latest phones, is a real breakthrough for some emergency services and has already saved many lives.[1] It also demonstrates the rapid progress being made in Sat-to-Cell technologies.

Space has often played an important role in the development of global telecommunications infrastructures. In the 1960s, communications satellites made it possible first to connect both sides of the Atlantic, and then the entire planet. From their geostationary position, they could transmit television broadcasts and telephone signals more efficiently than any other technology.[2]

Starting in the 1990s, the "information superhighway" became the Internet we know today. Mobile phones also came into widespread use during this same decade. These two technological revolutions have now merged into a single device, the smartphone, at once a telephone and a means of accessing the Internet.[3] Yet even as positioning satellites enabled the development of navigation services and telecommunications satellites served as a backhaul[4] solution for mobile networks, space has only had a marginal role to play in the development of these two technologies. Both predominantly rely on terrestrial infrastructures: telephones depend on relay antennas which are distributed across the grid, while the Internet's backbone consists of terrestrial and transoceanic cables which transmit nearly all of the global Internet traffic.

Until recently, all attempts at deploying Internet or telephone services via satellite resulted at best in the development of niche markets, at worst in failure. In the 1990s, a few companies ventured to offer satellite-based mobile phone services, but this market never developed, and most of them went bankrupt. Likewise, Internet access via geostationary satellites failed to attract any serious commercial interest, as technical limitations, including

1. R. Romme, "iPhone's SOS Satellite Feature Helped Rescue a Family of Hikers Lost in a Freezing Oregon Forest, Says Report", *Business Insider*, March 24, 2024, available at: www.businessinsider.com.
2. D. J. Wahlen, "Communications Satellites: Making the Global Village Possible", NASA, 2010, available at: www.nasa.gov.
3. A smartphone combines the functionality of a mobile phone (GSM) and of a mini-computer, enabling Internet access via mobile access points (4G, 5G), fixed access points (Wi-Fi) and satellite signal reception for positioning, timing and navigation (GPS, Galileo).
4. This refers to the part of the network that is not in contact with the end user, but acts as an interface between the user and the core network.

low bandwidth and high latency, prevented the technology from being adopted by the general public.[5]

Today, new technological advances make the development of such services an attractive prospect. This specific segment of satellite connectivity is generally referred to as "Direct-to-Device", "Direct-to-Cell" or "Sat-to-Cell".[6] It attracts both established players and new space ventures.

The goal is unlimited connectivity on land, sea or in the air, independent of cellular network coverage. Such a capability, accessible to every smartphone owner worldwide, would hold the promise of universal Internet access. It also subtly entails the possibility of breaking free from controls and restrictions put in place by countries like China, Iran and Russia, providing billions of people with new opportunities for emancipation.

Are such prospects credible, given the state of the art, regulations governing these infrastructures, and these technologies' duality? The aim of this study is to explore the geopolitical and economic stakes of these new uses, while taking into account the uncertainties that are inherent to any emerging sector. It will also provide recommendations and areas for consideration in order to leverage these developments at the European level.

5. Latency is the delay between a signal's transmission and the server's response. Because most satellites are located in geostationary orbit 36,000 kilometers (km) above the Earth's surface, they suffer from high latency, as signals take around 240 milliseconds to travel there and back, whereas a 4G network generally has a latency of between 30 and 70 milliseconds.

6. The name of this new sector is still being debated, mainly in the English-speaking world. "Device-to-Device", often abbreviated to "D2D", is the prevailing term, but it is a broader concept, encompassing Sat-to-Cell services as well as many Internet of Things (IoT)-related services that do not necessarily involve the use of smartphones.

The promise of universal connectivity

Iridium and Globalstar, 1990s pioneers

Beginning in the mid-1970s, the first generations of commercial geostationary satellites were primarily used for television broadcasting. Their numbers grew, accelerating in the 1980s and 1990s with the appearance of many public, and later private, carriers such as Intelsat, Eutelsat and SES. This enabled the consumer market to benefit from technologies which, just a few years earlier, were restricted to the military sector, among them satellite geolocation. In the early 1990s, the arrival of the first generations of mobile phones, and their popularity with consumers, gave hope that mobile telephony via satellite could grow into a major market.

The first private satellite phone companies, Globalstar and Iridium, thus emerged in the 1990s. These two entities, funded through partnerships[7], loans and large-scale fund-raising, each launched their own constellations of low-earth orbit satellites: 48 for Globalstar,[8] 77 for Iridium.[9]

But expectations surrounding satellite telephony failed to materialize in the early 2000s, and this market remained marginal. It relied on dedicated terminals, mobile devices that were larger and less ergonomic than traditional mobile phones, which were for their part experiencing exponential growth during this same period. The costs for end-users were higher than those of terrestrial operators. But above all, satellite phones suffered from severe operational limitations, with regular outages and little or no service in buildings or urban canyons.

These limitations relegated the technology to a few niche markets: military applications, emergency services, or long-haul ships operating far from terrestrial networks. This failure to penetrate mass markets considerably dampened the enthusiasm for this technology: faced with massive debts and results that failed to satisfy their creditors' expectations, both carriers went bankrupt, first Iridium in 1999, then Globalstar in 2003.[10]

7. In particular, Motorola for Iridium.
8. The first call was made in November 1998, and the network began operating in February 2000.
9. Vice President Al Gore was the first Iridium user, using one of their devices to call the great-grandson of Graham Bell, the inventor of the telephone, as part of a promotional campaign.
10. C. Mellow, "The Rise and Fall and Rise of Iridium", *Smithsonian Magazine*, September 2004, available at: www.smithsonianmag.com.

But both Globalstar and Iridium were bailed out and bought back[11]. Restructured to serve a tighter market, they were able to attract new investment to replace their aging satellites with new generation models with better capabilities. Globalstar was able to fund and deploy a second generation of 24 satellites between 2010 and 2013, with plans to send 17 more into orbit starting in 2025. Iridium has replaced its entire constellation, now known as Iridium Next, between 2017 and 2020, with a total of 72 satellites. These two carriers are now part of the Sat-to-Cell ecosystem, which is expanding in 2024 with new players like AST Spacemobile, Lynk Space and Starlink.

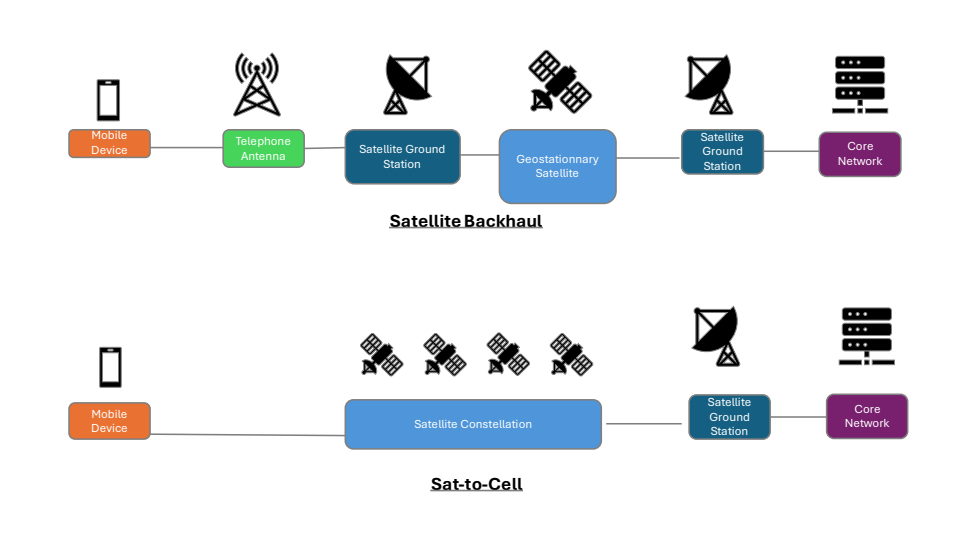
The steps leading to Sat-to-Cell

Satellites already play an important role as a backhaul system for current 5G networks. Satellites can be used to connect isolated cellular network towers which cannot be reached by fiber optics.[12] This type of connection is mainly used in developing countries.[13]

The next technological leap, known as Sat-to-Cell, is for smartphones to connect directly to satellites. Such a prospect opens up the possibility of universal connectivity in the near future, and ultimately the end of wireless dead zones across the globe. Today, over 90% of the world's population has access to terrestrial networks, but these cover only 40% of the Earth's landmass.[14]

11. "Iridium Back from the Dead", *Wired*, March 2001, www.wired.com.
12. "Backhaul Media for 5G and Beyond", *Ericsson Microwave Outlook Report*, 2023, available at: www.ericsson.com.
13. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.
14. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.

Satellite cellular connectivity architectures



Source: Diagram by Paul Wohrer © Ifri, 2024.

The evolution of Sat-to-Cell capabilities can be divided into three stages:

- The first stage is restricted to pre-recorded emergency text messages on phones equipped with this functionality. Such services are already available on the iPhone in the United States and should also be available in the new version of the Android operating system.
- The second stage features text messaging, multimedia messaging and satellite voice services. This type of service is available on the latest Huawei phones in China and could be available on iPhones in the fall[15].
- The third stage adds Internet connectivity to standard phones. Starlink conducted a successful test in May 2024.[16]

This third stage could make it possible to achieve complete "transparency" in telephone network use, leading to truly universal connectivity. Most of the businesses in the sector are focused on this final stage. By 2030-2040, it might therefore be possible to expect performances comparable to those of 3G+ networks, i.e., approximately 10 megabytes per second (Mb/s) downlink and 1 Mb/s uplink.[17]

Traditionally, a space system is composed of three segments: the space segment, i.e., its satellites; the ground segment, with stations which transmit and receive satellite data; and the user segment, e.g., satellite dishes, satellite telephones, IoT receivers, etc.

15. A. Mbida, "Téléphone portable : grâce aux satellites, les appels d'urgence sans réseau sont possibles sur certains mobiles", *France Info*, June 17, 2024, available at: www.francetvinfo.fr.
16. SpaceX Twitter (X) account, May 21, 2024, available at: https://x.com.
17. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.

Some operators have already reduced their ground segment requirements by deploying inter-satellite links. This has significantly reduced the number of ground stations necessary to maintain a satellite constellation network, thereby reducing terrestrial infrastructure costs. Automatic constellation management technologies also reduce the need for human operators involved in adjusting satellite positioning, for instance to avoid debris.[18]

The possibility of directly connecting to receivers, which more than half of the world's population already carry in their pockets, would also eliminate the need for dedicated user terminals, which are often costly and complex to develop.[19]

A disruptive innovation?

Disruptive innovation is a concept highlighted by Clayton Christensen, which sees certain innovations as having the ability to change the rules in an established market, usually by introducing a product or service that is less efficient and less reliable than those currently available, but which is more convenient and less expensive.[20] He contrasts it with incremental innovation, which involves improving the performance of a product within a given market. Performance in telecommunications is determined by data throughput and network latency: a network performs better when throughput is high and latency is low. This is what distinguishes the different mobile network generations, which have increased in performance through incremental innovation, from the first generation in the 1980s to today's 5G.

Sat-to-Cell combines many of the hallmarks of a disruptive innovation. Firstly, it is less efficient than terrestrial networks by today's standards: data throughput is lower and latency is higher. It is also less reliable: connection times are longer, coverage is limited inside buildings, weather conditions are a factor, etc.

But Sat-to-Cell's advantage is that it is available everywhere in the world, with no dead zones, even across oceans, at the poles and in the air. This unique feature could result in new applications and new expectations from consumers, such as the ability to use their phone wherever they are, whether abroad or in remote areas.

The big question that remains is how the cost of deploying satellite constellations compares with the cost of deploying 5G infrastructure. Some

18. C. Young, "SpaceX Starlink Satellites Have Made 50,000 Collision-avoidance Maneuvers", Interesting Engineering, July 7, 2023, available at: https://interestingengineering.com.
19. M. Shanahan and K. Bahia, "The State of Mobile Internet Connectivity Report 2023", *GSMA*, October 2023, available at: www.gsma.com.
20. C. Christensen, *The Innovator's Dilemma*, Boston, MA: Harvard Business School Press, 1997.

figures place worldwide investment for 5G at close to $1 trillion,[21] compared with a constellation like Starlink, which is estimated at $10 billion in 2024.[22]

In theory, disruptive innovations are more likely to succeed in markets where the performance of the products or services on offer exceeds customers' needs. Current Sat-to-Cell network performance is certainly not comparable to that of today's terrestrial networks. However, there are some indications that 5G networks may currently be outperforming market needs. Both *Les Échos*[23] and the *Wall Street Journal*[24] have described 5G as a "letdown", as consumers do not use the network to its full potential, through lack of need.

In addition, many dead zones still exist around the world - regions that are either too sparsely populated to be covered by mobile networks, or too poor for investment in infrastructure to be profitable. The presence of untapped markets could provide an opportunity for disruptive services to establish themselves.

The theory of disruptive innovation is not infallible and cannot predict Sat-to-Cell technology's success or failure. Also, compared to terrestrial networks, the development of state-of-the-art satellite capabilities cannot be reliably predicted in the short to medium term, which should be cause for caution. Nevertheless, current indicators do suggest that there is potential for new needs and new markets to emerge.

21. F. Fassot, "Réseaux 5G : 880 milliards de dollars d'investissement d'ici 2025", *VIPress*, March 9, 2020, available at: https://vipress.net.
22. P. Lionnet, "SpaceX and the Categorical Imperative to Achieve Low Launch Cost", *Space News*, June 7, 2024, available at: https://spacenews.com.
23. C. Praud, "5G: la grande déception?", *Les Échos*, March 6, 2024, available at: www.lesechos.fr.
24. J. Stern, "It's Not Just You: 5G Is a Big Letdown", *The Wall Street Journal*, January 11, 2023.

Geopolitical stakes of Sat-to-Cell

The end of online restrictions?

Many countries heavily monitor their citizens' Internet access. While China is the prime example, with the highly advanced surveillance systems of the "Golden Shield" project, sometimes referred to as China's "Great Firewall",[25] it is not the only country to keep a tight rein on its Internet activities. Iran, Russia, Vietnam, Cuba, Sudan, Venezuela… In all, there are 22 countries that do not have an open Internet, meaning that certain services are inaccessible to citizens and freedom of expression is severely repressed.[26]

Much of state authorities' power of coercion lies in their control over terrestrial infrastructures, e.g., optical cables, telecom operators, etc. A completely decentralized network, accessible from a simple cell phone, could therefore be more difficult to control. Transoceanic cables account for 99% of global connectivity, and their landing stations and the carriers managing them can come under state control. If no infrastructure is located within their borders, there is no way for them to control telecom operators, and repressive measures become more difficult to implement, short of imposing hardware or software restrictions on all smartphones in the country. However, such measures require considerable resources.

In theory, satellite services must comply with local regulations to operate in each country, or face being banned. The Federal Communications Commission (FCC), the U.S. telecommunications regulatory agency, reiterates this point in its Sat-to-Cell regulations: "We note that provision of any supplemental coverage from space outside the United States must be duly authorized by the relevant administrations and will be subject to laws, regulations and requirements applicable to such operations in the territories of the authorizing administrations".[27] States are thus authorized to suspend the service within their borders, under penalty of sanctions against any company that fails to comply with their injunctions.

In practice, this system is not perfect. A satellite service can theoretically be available everywhere on the planet. Restrictions are applied by the

25. The expression "Great Firewall of China" is a reference to the Great Wall of China.
26. A. Funk, A. Shahbaz et al., "Freedom on the Net 2023", *Freedom House*, 2023, available at: https://freedomhouse.org.
27. "Single Network Futures: Supplemental Coverage from Space", Federal Communications Commission, Washington, March 15, 2024, p. 100, available at: www.fcc.gov.

provider, by blocking access to the system through "geofencing".[28] This limitation is not intrinsic to the network, but a technical, and inconsistent, restriction. The Starlink constellation is a case in point: while it is not supposed to function in China, researchers have found that the service is in fact accessible in almost 90% of China's territory.[29] It has also been reported that the Russian military has used Starlink terminals during the war in Ukraine,[30] and that the service is accessible in many parts of Africa where it should not be operational.[31]

Sat-to-Cell capabilities could play an important role in destabilizing or influencing regimes, as was demonstrated using the Starlink constellation during the protests in Iran in 2022. The regime had cut off Internet access for the entire population. The White House then asked SpaceX to make the Starlink service available in Iran to allow the population to access the Internet and coordinate protests against the regime. However, the need for dedicated terminals, and to smuggle them into Iran,[32] as well as their easily detectable signals, limited the impact of this undertaking.[33] This would not be an issue with Sat-to-Cell technology, which requires no dedicated terminals, and could introduce new avenues for soft power.

One countermeasure would be to install technological barriers such as jammers. This is a relatively inexpensive and effective technology, which some countries already use to prevent broadcasts of television programs the regime condemns.[34] There is little public information on the capabilities and range of satellite jammers, however, given the sensitivity of such information. Depending on their effectiveness, they could completely block the use of such networks. In its annual report, the Secure World Foundation states that Russia can jam the Starlink network in its war in Ukraine[35]. It would also be possible to ban the use of mobile phones capable of accessing the Internet via satellite, but smartphones are inconspicuous devices, which are easily supplied through smuggling networks.

If Sat-to-Cell technology can help bring Internet access to areas without sufficient terrestrial infrastructure, it could also contribute to making the Internet more accessible in countries where the government tightly controls

28. Geofencing is the process of denying network access using geolocation information sent by the user.
29. "China Wary of SpaceX's Starlink Service during Taiwan Contingency", *Kyodo News*, May 25, 2024, available at: https://english.kyodonews.net.
30. A. Decker, "DOD: Russia's Use of Starlink Will Be a 'Continuous Problem' in Ukraine", *Defense One*, May 21, 2024, available at: www.defenseone.com.
31. L. Prinsloo et al., "Musk's Starlink Persists in Unauthorized Areas Despite Shutdown Warnings", *Bloomberg*, May 2, 2024, available at: www.bloomberg.com.
32. K. Vick, "Receivers for Elon Musk's Starlink Internet Are Being Smuggled into Iran", *Time*, October 22, 2022, available at: https://time.com.
33. N. Bertrand and A. Marquardt, "After Ukraine, Biden Administration Turns to Musk's Satellite Internet for Iran", CNN, October 21, 2022, available at: https://edition.cnn.com.
34. J. Rainbow, "Eutelsat Says Satellite Jammers Within Iran Are Disrupting Foreign Channels", *Space News*, October 7, 2022, available at: https://spacenews.com.
35. B. Weeden and V. Samson, "Global Counterspace Capabilities: An Open Source Assessment", Secure World Foundation, April 2024, pp. 2-26, available at: https://swfound.org.

it. This is an unprecedented development, which underscores the central role space companies now play in controlling data flows, rivalling that of governments.

Military applications of Sat-to-Cell technology

Space technologies are inherently dual, and Sat-to-Cell is no exception. The military, especially the U.S. military, has always been a key market for satellite operators. This was particularly the case for Iridium after its bankruptcy, with the U.S. military being one of the newly restructured company's few remaining prospects. For its part, the military has always relied on satellite services, which offer unrivalled mobility compared with terrestrial networks, to provide solutions which better satisfy its deployment needs, in particular for overseas operations.

Although the latest Sat-to-Cell solutions were neither initiated nor financed by the armed forces, they are nevertheless an attractive proposition for them. Colonel Eric Felt of the U.S. Space Force recently expressed his interest in this type of technology, which could enhance or even replace capabilities developed specifically for the armed forces.[36] His comments focused specifically on the MUOS (Mobile User Objective System), a marine communications service which has suffered numerous delays due to problems with the development of onshore receivers. His comments focused specifically on the MUOS (Mobile User Objective System), a marine communications service which has suffered numerous delays due to problems with the development of terrestrial receivers.

In March 2024, the Pentagon began a Sat-to-Cell service acquisition program,[37] and signed its first contract with Lynk in April 2024.[38] This is part of a trend which has been underway for several years in the United States, certain military operations being delegated to the private sector through service contracts, especially where New Space is concerned.

Limited European activity

At present, Sat-to-Cell technology is primarily developed by American and Chinese companies. Few integrators are promoting Sat-to-Cell as a future market, despite several European companies being involved in satellite manufacturing for Sat-to-Cell constellations.[39] French carrier Orange has

36. S. Erwin, "New Direct-to-cell Satellite Tech Could Disrupt Billion-dollar Military Satcom Programs", *Space News*, June 10, 2024, available at: https://spacenews.com.
37. T. Hitchens, "Space Force to Launch 'Marketplace' for Satellite-to-cellular Communications Services", *Breaking Defense*, March 3, 2023, available at: https://breakingdefense.com.
38. A. Weltman, "Lynk Global Signs Satellite-to-Cell Contract with US DoD", *Via Satellite*, April 25, 2024, available at: www.satellitetoday.com.
39. "Omnispace and Thales Alenia Space Announce Successful Launch of First Satellite Mission", Thales Group, Press Release, April 2, 2022, available at: www.thalesgroup.com.

entered a partnership with European operator One Web, but for backhaul solutions, not Sat-to-Cell.[40] Some equipment manufacturers are also working on these technologies, such as Germany's Alcan Systems, which supplies mobile phone antennas, and ST Microelectronic, which produces GaN components for satellite constellations.

This discretion is surprising, given that the sector is receiving a great deal of interest from analysts, as evidenced by the participation of European companies in the definition of Third Generation Partnership Project (3GPP) standards for Sat-to-Cell.[41] There are nonetheless several emerging European companies in the Sat-to-Cell field. For example, Spanish start-up Sateliot, whose satellites will combine Internet of Things (IoT) and 5G connectivity capabilities,[42] or Luxembourg-based OQ Technology, which is targeting the market and has ten Tiger satellites in orbit since March 2024, the "first batch" of its constellation.[43] Earlier this year, OQ Technology signed a contract with the European Space Agency (ESA) to assess the feasibility of a Sat-to-Cell system.[44] ESA is also increasingly interested in this area and has recently published calls for tender to delve into this technology.[45]

European companies are however much smaller and appear less ambitious than American start-ups, often positioning themselves more as IoT companies rather than Sat-to-Cell companies. The sovereign constellation being developed by the European Union (EU), IRIS², does not include this capability in its initial definition either.[46] The addition of Sat-to-Cell services to this constellation would open the way for innovative public services such as emergency messaging in dead zones. Such capabilities could also provide opportunities for cooperation with Africa, one of the IRIS² constellation's stated objectives. Smartphone penetration on the continent is in constant progression, with growth expected to reach 6.72% per year.[47]

40. "Orange et OneWeb signent un accord visant à améliorer et étendre la connectivité mondiale", Orange, Press Release, March 8, 2022, available at: https://newsroom.orange.com.
41. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.
42. J. Rainbow, "Spanish Startup Sateliot Seeks Funds for 64 More Connectivity Satellites", *Space News*, January 12, 2024, available at: https://spacenews.com.
43. "OQ Technology Successfully Completes Batch-1 with Two New 5G IoT Satellites Launch on Transporter-10", OQ Technology, Press Release, March 10, 2024, available at: www.oqtec.com.
44. "OQ Technology Signs Contract with ESA for Direct-to-Cell Feasibility Study", OQ Technology, Press Release, February 8, 2024, available at: www.oqtec.space.
45. "ESA Investigating Direct-to-Device", European Space Agency, April 6, 2024, available at: https://esastar-publication-ext.sso.esa.int.
46. Regulation (EU) 2023/588 of the European Parliament and of the Council of 15 March 2023 establishing the Union Secure Connectivity Programme for the period 2023-2027, available at: https://eur-lex.europa.eu
47. "Smartphones – Africa", Statista, available at: www.statista.com.

Key innovations for Sat-to-Cell

Advancements in satellite technology

Space architectures old and new

While today's Sat-to-Cell services still heavily depend on satellite services introduced in the early 2000s and dedicated telephones, innovative space start-ups are now entering the market. These companies have been able to leverage funding from mobile phone industry giants like AT&T, Vodafone and Google to drive their development.[48] Most of them offer an innovative service: Sat-to-Cell via conventional smartphones. The most important developments enabling the emergence of such services have come from the space industry, thanks in particular to reductions in launch costs and the industrialization of satellite manufacturing.[49]

AST Spacemobile, for example, was founded in 2017, and remained in the shadows until March 2020. UK group Vodafone and Japanese firm Rakuten then headed a $128 million investment to support the company's growth, then known as AST & Science.[50] The start-up then submitted a project for a constellation specifically dedicated to Sat-to-Cell, initially consisting of 243 satellites. AST Spacemobile became famous even before the launch of its functional prototype, BlueWalker-3, due to the size of its antenna, which spans 64 square meters (m^2), a feature that would make it particularly visible along its future orbit, at an altitude of 500 kilometers (km). But despite objections from astronomers, the satellite was launched on September 10, 2022. AST Spacemobile successfully completed its tests with BlueWalker-3 and relayed a phone call with an unmodified smartphone on April 25, 2023, demonstrating initial Sat-to-Cell capabilities. A few months later, the same prototype provided a 5G connection to an isolated off-grid device.

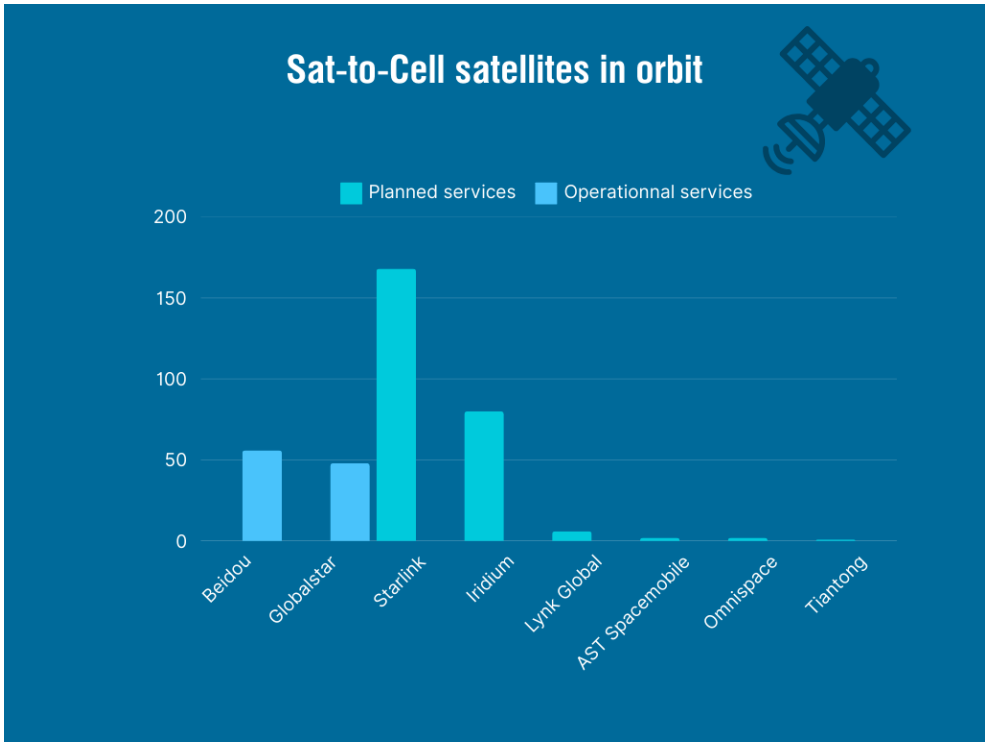
These tests demonstrate the technological relevance of these solutions: specialized satellite systems can provide connections to and from non-specific smartphones. AST Spacemobile plans to launch five new satellites into orbit. Its 2023 tests have attracted investors and secured the cash flow

48. "AST SpaceMobile Secures Strategic Investment from AT&T, Google and Vodafone", *Business Wire*, January 2024, available at: www.businesswire.com.
49. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.
50. "Rakuten and Vodafone Invest in AST & Science", ST Spacemobile, March 2020, available at: https://ast-science.com.

needed for production and launch. AST Space Mobile launched 5 satellites in September 2024.[51]

Other firms are close to launching their first services after successful demonstrations. This is the case for Lynk Global (formerly Ubiquitylink, a U.S. firm), which has at least six active "Lynk Tower" satellites operating at an altitude of 500 km. In addition to its core product, which aims for global coverage for its satellite messaging and emergency transmissions service (the company has also successfully tested calls on non-specific smartphones[52]), Lynk has several dozen partnerships and agreements around the world: Turkey, Argentina,[53] the United States, etc. U.S. companies currently dominate the industry, but a number of Chinese and European players are also emerging.

Leading companies and their satellite fleets



Source: Chart by Paul Wohrer © Ifri, 2024.

Expected impact of large constellations

Two major satellite constellations are already deployed or in the process of being deployed: OneWeb (634 satellites as of May 2023), owned by Eutelsat, and Starlink (over 6,000 operational satellites), owned by SpaceX. Other

51. "AST SpaceMobile Provides Interim Business Update to Confirm Upcoming Orbital Launch and Warrant Redemption", *Business Wire*, September 4, 2024, available at: www.businesswire.com.
52. R. Jewett, "Lynk Demonstrates Voice Calls Over Satellite", *Via Satellite*, July 2023, available at: www.satellitetoday.com.
53. M. Holmes, "Telefonica and Lynk Demonstrate Satellite to Cell in Argentina", *Via Satellite*, February 2024, available at: www.satellitetoday.com.

large constellation projects are under development, including Telesat (Canada), Amazon (USA), as well as Guowang (China) and IRIS² (Europe).

Given their data transfer capabilities, which are designed to minimize latency, low-earth orbit (LEO) connectivity constellations are especially well suited to the large-scale deployment of Sat-to-Cell communication services. However, with the exception of SpaceX, these companies are currently focusing on enterprise services. This is the case for OneWeb, which successfully tested a 5G connection with the University of Surrey in 2023,[54] or Amazon's future Kuiper constellation, which has a 5G network support agreement with carrier Vodafone.[55]

The most advanced constellation to date is SpaceX's Starlink. The Californian company headed by Elon Musk is in a commanding position with regard to the evolution of Sat-to-Cell.[56] SpaceX has privileged access to space, as it deploys its own satellites using its own launchers. This means the company can carry out launches "at cost", without any intermediaries and independent of any particular schedule other than that of its other clients.

SpaceX also mass-produces its Starlink satellites based on its own design and manufacturing processes, giving it a degree of control over the production cycle, procurement and on-board technology that its competitors cannot match. SpaceX can, for example, prototype new functions on a limited number of satellites, such as dedicated Sat-to-Cell transponders, which can then move into mass production. In February, the American firm announced that it had the capacity to build 55 satellites a week.[57] Starlink's competitors simply do not have such capabilities, and usually need to contract with satellite manufacturers to modify their payloads – provided they comply with launch constraints (volume, mass, links, etc.)

Starlink's connectivity service uses ground antennas, also produced by SpaceX, to provide Internet access. SpaceX's accounting is private, but according to founder Elon Musk, as of November 2023, the constellation's finances had broken even.[58] This statement was corroborated by Starlink vice-president Jonathan Hofeller, as well as Bloomberg, which projected global revenues of $15 billion for SpaceX in 2024.[59] Extending Starlink satellite capabilities to include Sat-to-Cell services therefore builds on existing revenue-generating assets.

54. "5G End-to-end Link First at ESA 5G Hub", ESA Connectivity & Secure Communications blog, European Space Agency, June 28, 2022, available at: https://connectivity.esa.int.
55. "Vodafone and Amazon's Project Kuiper to Extend Connectivity in Africa and Europe", Vodafone, Press Release, September 5, 2023, available at: www.vodafone.com.
56. D. Jones, "Can Direct-to-cell Satellite Services Make Money?", *Fierce Network*, June 21, 2024, available at: www.fierce-network.com.
57. J. Foust, "SpaceX to Deorbit 100 Older Starlink Satellites", *Space News*, February 2024, available at: https://spacenews.com.
58. Elon Musk's Twitter (X) account, November 2023, available at: https://twitter.com.
59. E. Ludlow and G. Tan, "SpaceX Eyes $15 Billion in 2024 Sales on Starlink Strength", *Bloomberg*, November 6, 2023, available at: www.bloomberg.com.

Thanks to these capabilities, SpaceX is making rapid progress towards commercial Sat-to-Cell offerings. On August 22, 2022,[60] SpaceX announced a new partnership with T-Mobile in the United States, using Starlink satellites for unmodified consumer smartphones, using a 4G frequency band. On January 3, 2024, the first series of six modified Starlink satellites went into orbit.[61] Sat-to-Cell service for a consumer messaging application is announced for 2024, with eight partner carriers in different countries. For now, SpaceX is announcing expansions into telephony, IoT and data transfers (i.e., 4G Internet access) by 2025.[62]

The company operates as an Internet service provider, with no intermediaries, functioning through a proprietary solution. It markets its antennas and service plans and manages its entire infrastructure. The Californian firm has strongly invested in Sat-to-Cell technologies. As of September 2024, it operates more than 150 Sat-to-Cell satellites,[63] and plans to roll out call and data services starting in 2025. On August 27, 2024, Elon Musk announced his intention to provide free satellite emergency call capabilities across the globe, pending governmental authorizations.[64] This company is one to watch, as it could be a major player in the development of Sat-to-Cell technology in the months and years to come, potentially resulting in a monopoly.

Advances in terrestrial receivers

A close cousin of the Internet of Things

A number of technical innovations were necessary in order for unmodified smartphones to be able to connect to orbital constellations. Early ventures in satellite telephony paved the way, but they relied on dedicated terminals equipped with bulky antennas. In the past twenty years, other objects capable of communicating with constellations have gradually become smaller and more widespread, including geopositioning equipment (receivers only), which has been integrated into a wide range of consumer products: connected watches, smartphones, vehicles, etc.

More recently, some small devices have also become capable of "uplink" communications with satellites. For over forty years, the progressive miniaturization of these connected objects has paved the way for Sat-to-Cell. The most well-known examples in France are Argos beacons. Originally designed to locate navigators at sea, they gradually adapted to be able to track

60. "T-Mobile Takes Coverage Above and Beyond with SpaceX", T-mobile, Press Release, August 2022, available at: www.t-mobile.com.
61. J. Rainbow, "SpaceX Deploys Direct-to-smartphone Satellites in First Launch of 2024", January 2024, available at: https://spacenews.com.
62. "Starlink Direct to Cell", *Starlink Blog*, available at: www.starlink.com.
63. Celestrack data, available at: https://celestrak.org.
64. Elon Musk's Twitter (X) account, August 27, 2024, available at: https://x.com.

a wide range of animal species, transmitting short signals decoded by satellites and relayed to a data center. As of 2009, the smallest Argos beacons, equipped with very thin solar panels, a battery and a small antenna, weigh only five grams.[65]

These advances in ground transmitters have since expanded into space, with the integration of Argos units in several generations of satellites, including those operated by Kinéis. In 2020, the company's CEO predicted growing demand for connected objects.[66] From fishing and recreational boats to drilling sites, high-voltage power lines, agriculture and forest fire detection, the list of potential applications grows as access to this technology expands and costs fall. This market is already very competitive: besides Kinéis, Swiss firm Astrocast, and the Chinese GeeSpace constellation (Geely Future Mobility Constellation)[67] are also active. The latter, aimed specifically at the automotive sector, will provide positioning and connectivity services, with the dual objective of vehicle connectivity for autonomous driving and Sat-to-Cell type services. The goals of Sat-to-Cell and IoT thus appear to overlap: connecting ever-smaller objects via satellite networks.

IoT generally runs on low-bandwidth frequencies that only allow small amounts of data to be transmitted. There are, however, some bridges emerging between IoT and Sat-to-Cell, with services branded as '5G IoT', which several satellite operators are starting to deploy to serve areas without connectivity.[68]

Such technological bridges also drive the need to acquire patents and capabilities. For example, U.S. company Swarm, founded in 2016 and specialized in IoT, was acquired by SpaceX. It had developed a constellation of extremely small nanosatellites (11 x 11 x 3 centimeters), which could not be controlled, but could be produced and launched in clusters. With 120 units in orbit, the start-up was able to successfully connect to ground-based sensors, before being acquired by SpaceX in 2021, the only acquisition made by Elon Musk's firm.[69] Swarm's two founders are now senior engineers on the Starlink project.[70]

Advances of Sat-to-Cell in smartphones

The launch of the Apple iPhone 14 in 2022 marked a turning point in the consumer smartphone sector. Apple unveiled a partnership with the

65. C. D., "Balise Argos, la planète mode d'emploi", *Le Figaro*, October 2009, available at www.lefigaro.fr.
66. J. Lepretre, "Kinéis prévoit d'envoyer 25 satellites pour révolutionner l'IoT", BPI France, March 2024, available at: https://bigmedia.bpifrance.fr.
67. "China's Geespace Launches Eleven Low-orbit Satellites to Build Geely Future Mobility Constellation", *Iot Business News*, February 2024, available at: https://iotbusinessnews.com.
68. A. Hillier, "Satellite IoT for 5G - What's the Story?", *TTP*, April 24, 2019, available at: www.ttp.com.
69. M. Sheetz, "SpaceX Acquiring Satellite Data Start-up swarm Technologies", CNBC, August 9, 2021, available at: www.cnbc.com.
70. A. Alamalhodaei, "SpaceX's Acquisition of Swarm Is Paying Off with New Starlink Thrusters", *Techcrunch*, March 3, 2023, available at: https://techcrunch.com.

Globalstar constellation for a satellite SOS service, connecting to smartphones located outside of the terrestrial grid via satellite coverage to transmit messages to an emergency server.

Initially restricted to the United States and Canada, this free service will be extended in 2024 to many European countries, as well as Australia and New Zealand.[71] Since it was introduced, many articles have reported on users being rescued thanks to this new feature: lost hikers, workers caught in a blizzard, and a family trapped by a forest fire that had knocked out terrestrial networks.[72] For the general public, this is the most prominent demonstration of Sat-to-Cell services.

For Apple, this represents a major investment, even with its substantial financial resources: for this service to work, the company had to adapt its new phone. It has also secured 85% of the Globalstar constellation's capacity and is covering 95% of the cost for the order of 17 new satellites, totaling more than $300 million, to extend in-orbit capacity.[73] These satellites will not be operational until late 2025 at the earliest, which also represents a medium-term commitment to Globalstar for Apple.

This technology has many limitations. The actual connection can take several minutes to establish and can only be used to send a message in a predetermined format. Apple also chose to modify its hardware to enable it to connect to a constellation.[74]

The announcement of the iPhone 14 seems to have spurred some competitors to introduce similar services. In August 2023, Chinese manufacturer Huawei presented its Mate 60 Pro model, equipped with a dedicated chip and hardware modifications to enable it to send text messages and make calls. The company is unique because it relies on an existing constellation of Chinese Tiantong-1 satellites, located in geostationary orbit and covering the Asia-Pacific region.[75]

In January 2023, microchip manufacturer Qualcomm announced a partnership with the Iridium constellation, to create a chip that would offer an emergency messaging service, as well as the ability to send short text

71. "Use Emergency SOS via Satellite on Your Smartphone", Apple Support, March 2024, available at: https://support.apple.com.
72. F. Ion, "Family Escapes Maui Fires Using Apple's Emergency SOS", *Gizmodo*, August 10, 2023, available at: https://gizmodo.com.
73. J. Foust, "Apple to Be Largest User of Globalstar's Satellite Network for iPhone Messaging", September 2022, available at: https://spacenews.com.
74. Other manufacturers are avoiding the complications involved in integrating hardware to connect to satellite networks by selling stand-alone Bluetooth devices which, for a monthly subscription fee, allow users to send messages via satellite, or to activate a pre-formatted backup message, as with Apple's product. One such device is Motorola's Defy Satellite Link.
75. "Huawei Mate 60 Pro Is the World's First Satellite Calling Phone", Huawei, August 29, 2023, available at: www.huaweicentral.com.

messages while out of range of the terrestrial grid.[76] Eleven months after this announcement, the partnership was discontinued despite successful demonstrations, as smartphone manufacturers elected not to include this technology in their devices.[77] This decision was not necessarily due to a lack of demand, but rather a result of other Sat-to-Cell demonstrations using unmodified smartphones, without dedicated chips or antennas, in accordance with the latest 3GPP standards.[78] The latest versions of the Android and iOS operating systems also seem to indicate that Sat-to-Cell capabilities should become increasingly widespread on these devices.[79]

Changes in standards and regulations

3GPP, the main industry consortium responsible for defining mobile telecommunications standards, has incorporated satellites into its latest publications.[80] Labeled as NTNs (Non-Terrestrial Networks), these services are now officially included in telecom operators' technology development roadmaps. Deployed in a limited capacity as part of 5G, they could become a crucial component of 6G infrastructure. These standards have no regulatory power, but they embody the objectives shared by the majority of the world's telecom operators and have a direct impact on the regulations adopted by the International Telecommunication Union (ITU).[81] A consensus now seems to have emerged regarding the importance of satellites for future telecommunications networks.[82]

In March 2024, the FCC, the U.S. telecommunications regulatory agency, approved a new regulatory framework entitled "Supplemental Coverage from Space",[83] marking a regulatory turning point. These regulations allow operators of space-based services to make use of frequencies normally reserved for terrestrial operators, on an experimental basis. Space-based carriers would, however, be required to cease operations should they interfere with terrestrial services. The stated aim of these new rules is to eliminate dead zones and make emergency services available in

76. "Qualcomm Introduces Snapdragon Satellite, the World's First Satellite-Based Solution Capable of Supporting Two-Way Messaging for Premium Smartphones and Beyond", Qualcomm, Press Release, January 5, 2023, available at: www.qualcomm.com.
77. M. Sheetz, "Iridium, Qualcomm End Satellite-to-phone Partnership", CNBC, November 9, 2023, available at: www.cnbc.com.
78. "Release 17", 3GPP, March 2021, available at: www.3gpp.org.
79. M. Rahman, "Android 15 Might Let You Send Text Messages Via Satellite", Android Authority, March 2024, available at: www.androidauthority.com.
80. "Release 17", 3GPP, March 2021, available at: www.3gpp.org.
81. The International Telecommunication Union is the organization responsible for harmonizing frequency bands and coordinating spectrum use to avoid harmful interference. It meets every three to four years at the World Radiocommunication Conference, where new harmonization measures are decided.
82. Research interview with a telecommunications and space industry specialist, Ifri, August 1, 2024.
83. J. Rainbow, "FCC Approves Direct-to-smartphone Regulatory Framework", *Space News*, March 14, 2024, available at: https://spacenews.com.

areas not covered by satellite services.[84] Companies wishing to use these services must apply to the FCC for authorization and prove that they will not interfere with terrestrial networks. These regulations were an encouraging development for several start-ups still at the trial stage.

In these regulations, the FCC expresses its intention to harmonize international regulations in favor of Sat-to-Cell through the ITU. The FCC thus recommends that the next World Radiocommunication Conference,[85] to be held in 2027, includes the topic of frequency band allocation for Sat-to-Cell.[86]

84. "Single Network Futures: Supplemental Coverage from Space", Federal Communications Commission, March 15, 2024, available at: www.fcc.gov.
85. The World Radiocommunication Conferences are held every three or four years to review international communications regulations and coordinate the use of the frequency spectrum. They are organized by the International Telecommunication Union, the United Nations agency specialized in information and communication technologies.
86. FCC, *op. cit.* p. 24-28.

Sat-to-Cell's uncertain future

A technology still in its infancy

Although public demonstrations in 2023 and 2024 confirmed its performance in theory, Sat-to-Cell today remains a young technology. The most mature solutions in 2024 are very limited, ranging from pre-formatted emergency messages to text messaging.

Sending times for messages can take several minutes or more, and only very small amounts of data can be sent or received (excluding demos). The clientele is a niche group, that is people without specialized equipment who would need to call for help or contact their loved ones in an emergency situation in a dead zone. Customers with a genuine need for satellite telephony capabilities, such as sailors and military personnel, still purchase specialized equipment. It is not yet known what level of performance Sat-to-Cell will achieve in the long term.

Besides its modest performance, there are also physical limitations that make this technology's implementation more complex. While constellations do not suffer from the latency that plagues geostationary satellites, the satellites' rotation around the Earth induces a Doppler effect.[87] While this effect is negligible for terrestrial networks, it complicates the process of connecting to standard telephones. This requires software designed to "trick" the phone into thinking it is communicating with a terrestrial telephone antenna, considerably closer than a satellite orbiting at an altitude of 500 km.[88] Most Sat-to-Cell companies claim to have overcome this problem.

Still, Sat-to-Cell suffers from connection difficulties in buildings, under tree cover or in inclement weather. What's more, cell phones connected to a satellite need to increase their transmission power, which can have an impact on battery life. During testing, AST SpaceMobile reported that these effects were negligible.[89]

87. The Doppler effect is a natural phenomenon that occurs when a source of vibration or radiation (sound, light, radio waves, etc.) moves relative to an observer. For constellations, this phenomenon is exacerbated by the relative speed between the satellites and the receivers (28,000 km/h) and by the high frequencies used for communication (Ku and Ka bands, or even Q or V bands).

88. L. Bernstein, "Outsmarting Smartphones with Cell Towers in Space", Kratos Defense, July 26, 2022, available at: www.kratosdefense.com.

89. K. L. Jones and A. L. Allison, "The Great Convergence and the Future of Satellite-enabled Direct-to-device", Aerospace Center for Space Policy and Strategy, September 2023, available at: https://csps.aerospace.org.

Risk of interference with terrestrial operators

For more than two decades, Telecom operators, whether private or state-owned, have been providing, through their networks of terrestrial antennas, a service that only they can offer. These carriers regulate their customers' access to messaging, telephony and connectivity services across the terrestrial network, including in France, where the four major telecom operators are also Internet providers.

But with Starlink's arrival on the market, this picture is beginning to change. In the past, satellite services were mainly used to cover relatively small dead zones, but these constellations now offer the opportunity to reach entire regions not yet connected to the fiber-optic network, as well as the oceans and poles. During the preparation of the international 5G standards, as well as the adoption of the FCC regulations, companies in the terrestrial and space sectors fought to acquire or share frequency bands in what were sometimes heated exchanges.[90]

Some see this as an opportunity to gain market share through partnerships, as was the case for Verizon, T-Mobile, or Vodafone. With technical trials still ongoing, their goal is to enter the market before anyone else. They want to be able to offer a groundbreaking new service that will attract customers, which the competition will need time to catch up to. Choosing the right satellite operator and good terms will be crucial. Operators working with the future Kuiper constellation, for example, would only be able to offer Sat-to-Cell services starting in 2025 at the earliest. Likewise, Apple's services will have few opportunities to expand with Globalstar satellites until new units are put into orbit.

While the FCC's new Sat-to-Cell regulations were welcomed by start-ups, the same cannot be said for legacy carriers. The latter have expressed some reservations about the implementation of these new regulations: DISH, Echostar Global, Hughes Network and Echostar Mobile Limited submitted a joint statement to the FCC urging caution, in particular regarding the frequencies to be allocated to Sat-to-Cell services. This was also the case for start-up Omnispace, which claimed that FCC regulations ran counter to the principles agreed upon by the ITU, and that interference was a major risk, in particular for its own Sat-to-Cell solution. Carriers TerreStar, DISH Networks and AT&T echoed these concerns.

Terrestrial telecom operators thus have good reason to be apprehensive about the emergence of new Sat-to-Cell services. These are systems they neither own nor operate. If satellite operators are courting them today, it is

90. M. Homes, "'Ludicrous and Ridiculous' – CEOs React to Intelsat's 5G Proposal", *Via Satellite*, October 10, 2017, available at: www.satellitetoday.com.

because they hold control of infrastructure and, more important still, of frequency bands. We can therefore distinguish between new satellite operators intending to deliver their services over frequency bands reserved for satellites, and those seeking to use frequencies assigned to terrestrial infrastructures. The allocation of the electromagnetic spectrum is therefore likely to become a battleground between legacy carriers and emerging competitors over the next few years.

Market uncertainties

Revenue from satellite communications totaled $110 billion in 2022. But the satellite telecom sector has been shrinking for several years, due to the decline of satellite TV, which still constitutes most of its business: without it, revenues in the satellite telecom sector only amount to $28 billion.[91] The sector therefore needs a new growth driver, and satellite connectivity (including Sat-to-Cell) appears promising. Northern Sky Research estimates that by 2030, the Direct-to-Device market could generate nearly $70 billion in combined revenue over ten years. It is effectively the convergence of the satellite telecommunications market, worth $110 billion, and the terrestrial telecommunications market, worth over $1 trillion.[92]

This emerging market carries opportunities but also risks.[93] The failed partnership between Qualcomm and Iridium[94] is a case in point: smartphone manufacturers and OEMs' reluctance to invest in this range of chipsets may be due either to their high cost, which could not be passed on to consumers, or to the hardware's specificity, which manufacturers could not justify based on demand. In other words, if Sat-to-Cell requires smartphone manufacturers to modify their devices specifically to enable these connections, they will need a return on investment. Hence the interest in solutions capable of connecting unmodified devices.

The tipping point for Sat-to-Cell would be truly seamless use for the general public: being able to keep using the same smartphone in an area with no 3G or 4G coverage.[95] Sat-to-Cell could function as part of a network that relies less on terrestrial antennas, one technological building block among others, much like Wi-Fi routers, for example. The real potential of Sat-to-Cell lies in its integration within a connectivity ecosystem incorporating both conventional telephone networks and satellite connectivity networks.

91. K. L. Jones and A. L. Allison, "The Great Convergence and the Future of Satellite-enabled Direct-to-device", op. cit.
92. Ibid.
93. J. Foust, "A Trillion-dollar Space Industry Will Require New Markets", *Space News*, July 5, 2018, available at: https://spacenews.com.
94. N. Flaherty, "Qualcomm annule son accord avec Iridium sur les puces pour satellites", *Ecinews*, November 12, 2023, available at: www.ecinews.fr.
95. "5G satellite, accélérer la convergence des réseaux de télécommunication terrestres et satellitaires", Capgemini, available at: www.capgemini.com.

Apple's adoption of satellite messaging, the ongoing development of these services and their planned expansion, all point to the prospect of market penetration for satellite operators capable of partnering with the right terrestrial carrier, should their offer be competitive. For the moment, this market is hypothetical. Apple's emergency messaging service, the most widespread service at this time, is free of charge and should not become a paying service before 2025-2026. The most highly anticipated satellite services, such as SpaceX's Starlink, have not yet been priced. Research on demand will therefore also need to be accompanied by the close examination of these new services' pricing and business models.

The latest versions of both the Apple and Android operating systems now include a satellite messaging feature, and SpaceX has plans for 2025. All these developments seem to indicate that Sat-to-Cell services will be available in the short to medium term. Despite many uncertainties, Euroconsult, a private group, estimated in a report published in November 2023 that the Sat-to-Cell market alone would generate over one billion dollars in sales by 2027, with over 130 million monthly users by 2032.[96]

96. "Direct-to-phone Satellite Connectivity Expected to Revolutionize the Satellite Communications Industry, Emerging as a Billion-dollar Market by 2027", Euroconsult, Press Release, November 2023, available at: www.euroconsult-ec.com.

Conclusion

Sat-to-Cell is a new type of satellite service with unprecedented potential. While the idea of connecting telephones via satellites is not new, recent technological developments have made it possible to envision their widespread use. Most of this progress has been made in the space industry, which is now able to industrialize the production of launchers and satellites, offering better services at lower costs. In this emerging competitive landscape, SpaceX seems to be in a class of its own, thanks to its strong vertical integration, its at-cost access to space and its rapid prototyping capabilities.

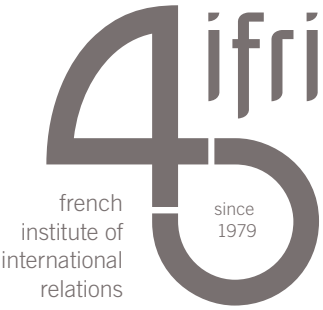
Considering the current landscape of Sat-to-Cell in 2024, this study has not addressed certain aspects of its operation and the challenges raised by connectivity constellations, such as their high visibility in the night sky, which astronomers have decried, and their vulnerability to in-orbit collisions. The cascade effect, which could result, would be a hazard for the orbital plane at their given altitude. These risks will grow, particularly for constellations numbering several thousand units and which, given the meshing and altitudes involved (generally less than 550 km above sea level), could impact all low-earth orbit operators.[97]

The success of Sat-to-Cell could depend on a multitude of factors, not least its regulatory framework and partnerships with terrestrial carriers. Its business model still raises many questions, but international standards and regulations are evolving to facilitate its emergence. The iOS18 update unveiled by Apple in September 2024 now includes a satellite messaging service which is no longer limited to emergency messages. These new services could complement terrestrial mobile networks, or even compete with them in certain regions.

The impact this technology will have on the geopolitics of telecommunications networks is still uncertain. While the control certain states exert over Internet access could be challenged by such a service, countermeasures targeting Sat-to-Cell could render its impact negligible in this regard. Military forces are nevertheless looking into this technology, which can provide an additional means of communication, making their communications infrastructures more resilient.

97. Wei Zhand et al., "Self-induced Collision Risk of the Starlink Constellation Based on Long-term Orbital Evolution Analysis", *Astrodynamics*, August 2023.

Sat-to-Cell is currently predominantly developed by American, and to a lesser extent, Chinese companies. European development is still very limited, despite the potential of such systems. They could be used to develop new kinds of public services: the introduction of a Sat-to-Cell emergency service, for example, could address needs that have already been identified in Europe. These services should also be prevented from becoming monopolized by foreign companies, to avoid a loss of sovereignty. Experimenting with Sat-to-Cell capabilities with the IRIS² constellation would provide an opportunity to gain a better understanding of these technologies, assess their potential impact, and prevent Europe from being excluded from a hypothetical yet promising market.



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