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THE GREAT CONVERGENCE AND THE FUTURE OF SATELLITE-ENABLED DIRECT-TO-DEVICE

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The satellite-powered Direct-to-Device (D2D) market has emerged as the next big thing for the telecommunications sector and it depends upon the convergence of services from satellite operators, terrestrial mobile network operators (MNOs), and the global Internet of Things (IoT) market. This paper examines D2D innovators and leaders along with technology and regulatory drivers that could advance or delay the market state of play. To understand this nascent D2D market, one must also evaluate strategic partnerships and regulatory issues, including spectrum access and licensing. Many successful demonstrations have already proven the technical feasibility of connecting satellites and off-the-shelf consumer grade cell phones, but questions of scalability and the market for low data rate services remain.

D2D providers intend to enhance wireless connectivity in areas unserved by terrestrial wireless networks. This market will grow gradually first with applications that require lower throughput, such as emergency messaging and two-way texting, and later the market could potentially expand to higher bandwidth applications. The wild cards hanging over D2D services are what business models will dominate, how large is the addressable market, and the degree to which competition, cooperation, and disruption will shape the D2D landscape. In the meantime, this analysis provides a framework for understanding the market players, trends, and drivers.

Direct-to-Device (D2D)

Supplemental coverage from space to consumer-grade cell phones or Internet of Things (IoT) devices using non-terrestrial networks (NTN) from non-geostationary Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) systems, and Geostationary Orbit (GSO) networks.*

Strengths	Weaknesses
Market Ubiquity. Mobile and satellite network operators, and IoT providers can respond to customers' increasing need for anywhere seamless connectivity. D2D allows coverage to underserved, remote, and disaster areas. **Mobile Network Operator (MNO) Synergy with Satellite Operators.** • Expands MNO reach to remote areas with satellite coverage while eliminating costs associated with cell site deployment. • Expands satellite services to large MNO customer base while leveraging existing MNO support systems (legal, customer support, etc.). ***Terrestrial Satellite Convergence.*** Allows a shift from expensive custom solutions to international industry consortium standards, enabling enhanced interoperability across satellite and MNO networks.	***Market Uncertainty.*** Despite significant upside revenue potential for satellite operators, MNOs and IoT applications, market adoption rates are not yet proven. Internationally, customer price elasticity varies significantly. **MNO and Satellite Integration – Time, Capital, and Regulatory Approvals.** • Some D2D architectures need specialized chipsets embedded in consumer grade phones. • D2D providers planning to reuse terrestrial MNO spectrum from space will require regulatory changes or waivers to obtain necessary national authorizations and demonstration that they will not cause harmful interference to other systems. ***Technical Complexity.*** D2D providers using LEO satellites will need to manage Doppler shift and latency, although, D2D data and voice demonstrations have overcome these challenges with unmodified cell phones.

*D2D could involve high altitude platform stations (HAPS) including fixed-wing aircraft, balloons, and airships, operating in the Earth's stratosphere.

Introduction

Almost 86 percent of the world's population carries a smartphone.[†] The number of smartphone subscribers worldwide reached almost 6.9 billion in 2023, with the leading smartphone manufacturers being Apple and Samsung.[1] Smartphone users depend upon connectivity offered by terrestrial network service providers, often referred to as a mobile network operators (MNOs) or wireless carriers, to enable the phone to make and receive texts and calls as well as access a boundless range of mobile data applications, cloud connectivity, and internet of things (IoT) applications, using low power and low cost sensors. And yet, even with the robust build-out of towers and fiber, dead spots remain across large swaths of the planet —particularly in rural, remote, and maritime areas.

To address unserved users within these geographies, two very different markets, satellite and terrestrial communications,[‡] are starting to collaborate and integrate connectivity services. Outwardly, the satellite communication or "satcom" and terrestrial wireless industries have long appeared to be competing cultures and technologies. But U.S. Federal Communications Commission (FCC) Chairwoman Jessica Rosenworcel recently emphasized that both industries now have an opportunity to move beyond siloed thinking and to collaborate and encourage efficient use of spectrum.[2]

The FCC's proposed regulatory framework for "supplemental coverage from space," would allow a satellite operator to partner with a terrestrial mobile licensee to use their terrestrial spectrum—allowing the satellite system to provide service directly to the wireless carrier (also referred to as MNO) in areas where the terrestrial carrier lacks coverage. Notwithstanding the FCC's position, some incumbent spectrum licensees, including wireless operators, have voiced concerns over the sudden departure from traditional spectrum management practices posed by D2D providers reusing spectrum approved only for **terrestrial** operations for transmission from satellites in **space**. Such use would be counter not only to current U.S. regulations, but also to the international Radio Regulations, a treaty on spectrum use of which the United States is a signatory.

This emerging wireless service offering from space is still evolving in commercial markets. Industry players and regulators have not coalesced around a single term for it. This paper will use the term *Direct-to-Device* or "D2D" to refer to this satellite/terrestrial wireless service convergence. However, other terms also apply. The FCC refers to this fledgling service as *Supplemental Coverage from Space* (SCS). Others have referred to it as *Direct-to-Cell Phone*. Recently, the term Direct-to-Device has gained popularity because the device could be either a cell phone, a tablet, an IoT transponder, or another type of wireless-enabled form factor. Terminology notwithstanding, a converged market offers the potential for more customers and revenues for both satellite and terrestrial wireless communication and IoT providers. Moreover, future 6G networks will build on 5G standards to further unify terrestrial and satellite networks—making converged and ubiquitous networks inevitable.

Note: *A glossary of terms and acronyms can be found at the end of this paper. Authors chose to use the term GSO (geostationary satellite orbit) instead of GEO (geosynchronous orbit) and NGSO (non-geostationary orbit) instead of LEO (low Earth orbit) and MEO (medium Earth orbit) because these are the preferred terms used by ITU and other spectrum regulatory bodies.*

Background—Convergence Trends

The connectivity sector (such as cable, fiberoptics, MNOs[§] (Mobile Network Operators), IoT, and satellite providers) is reaching a new level of convergence and maturity, enabled by internet-based technologies and protocols. As one telecommunications pundit noted, "In the future, you won't necessarily know where your connectivity is coming from...your devices will simply attach to available resources."[3]

Satellite, terrestrial wireless, and fiberoptic providers are seeking to strengthen market position and meet consumer

[†]A device that combines the functions of a cell phone with a handheld computer, typically offering internet access, data storage, email capability, and applications.
[‡]Terrestrial wireless services could include fixed or mobile wireless services.
[§]Also known as carrier service providers, mobile phone operators, or mobile network carriers.

expectations by providing seamless access across a range of network options. This convergence of wireless services is perhaps no surprise to the systems engineering community where studies and efforts have supported evolving technical frameworks and have defined how systems can work together to meet objectives. Such frameworks emphasize open interfaces to work together and modularity whereby each system is to some extent independent of others. The one principle that stands out as highly applicable for D2D networks is the synergism principle that "designates that the co-operative interaction between constituent systems has a greater effect in their combined efforts than the sum of their individual parts."[4] Synergism is occurring across the connectivity sector. Examples of expanding "network of networks" include:

- **Cable companies + MNOs.** Comcast and Charter Cable are beginning to offer wireless services and other cable companies have signaled an interest in mobile.[5] Likewise MNOs, such as Verizon and T-Mobile, are urging potential customers to "ditch cable" and join their bundled home internet plans.[6]

- **MNO + IoT.** Deutsche Telekom is working with satellite network operators Intelsat and Skylo to offer a global IoT network, planned for the second quarter of 2023.[7] Use cases include monitoring wind turbines in remote regions, recording water levels and weather data in remote locations, and high-performance broadband connections on the high seas.

- **IoT + Satcom.** A recent example involves Swarm, a global LEO constellation operating small "sandwich-sized" satellites to provide low-cost low-bandwidth connectivity. Swarm's founder highlighted that the combined support systems with Starlink, such as "legal, accounting, HR, recruiting, logistics, supply chain and production" helped to scale up their business. Conversely, Starlink can diversify its product offerings to include lower cost services. While it is not yet clear how the networks will converge, SpaceX's Starlink website is already advertising Swarm satellite IoT connectivity.[8]

- **Satcom + MNOs.** Despite the steady pace of network expansions and convergence, unserved and underserved areas remain.[**] Satellite operators offering D2D can enhance wireless connectivity in areas unserved by terrestrial wireless networks. This is why terrestrial cellular and satellite operators are now motivated to collaborate, including:

  - *Satellite operators* – using LEO, MEO or GSO networks, are licensed to operate in Mobile Satellite Service (MSS) or Fixed Satellite Service (FSS) allocations.[††] However, the satellite subscriber base is very small compared to the 6.9 billion people currently carrying smartphones and represents a significant additional addressable market for the satcom sector.

  - *MNOs* – licensed to operate in frequency bands allocated for terrestrial mobile services and have invested millions or billions of dollars at government auctions for spectrum access in specific geographical areas. MNOs, such as T-Mobile, Verizon, and AT&T, are seeking to address network coverage gaps where a cell tower is not feasible or profitable. For some unserved and underserved areas, satellites can fill the coverage gap.

In addition to the growing convergence among cable companies, MNOs, IoT, and satcom, the lines are also blurring between the fixed-satellite service (FSS) and mobile satellite service (MSS). The governing approach for MSS and FSS harkens back to a time when legacy equipment, technology maturity, and mobile services justified separate spectrum allocations and regulatory approaches. But today, the distinction between "fixed" and "mobile" is blurred and many industry players advocate for more flexible regulations. Likewise, spectrum regulators such as the FCC are changing regulations and granting applications with conditions to meet growing user demands for broadband capabilities while on the move. To this end, the evolving regulation of new services such as

[**]Unserved areas have no cellular reception and underserved have slow, spotty, or not ideal internet access.
[††]Iridium and Globalstar are both MSS LEO systems. Starlink is a LEO FSS system and ViaSat is a GSO FSS system. Fixed Satellite Services (FSS) use ground equipment at set locations to support voice, data and video, including internet services. Mobile Satellite Services (MSS) offer communication services on mobile platforms, including land mobile, maritime, and aeronautical customers.

Earth Stations in Motion (ESIMs), a collective designation for Earth stations on moving platforms, may provide some insight into how satellite D2D might evolve over time. Although serving mobile Earth stations, ESIMs communicate via GSO networks operating in the **fixed**-satellite service. These ESIMs offer services traditionally provided by MSS systems, such as Inmarsat and Iridium, but in higher FSS frequencies.

Earth Stations in Motion (ESIMs): Evolving Regulatory Flexibility

Traditionally, FSS involves communications between orbiting satellites and Earth stations at **fixed** locations. However, new smaller terminals with high-precision tracking capabilities are now available and can be attached to moving platforms such as aircraft, ships, and vehicles. These terminals can connect to Ku- and Ka-band geostationary satellite orbit (GSO) satellites which provide high power, multiple spot beam coverage.

In response to the growing demand for ubiquitous broadband communications and increased use of FSS for mobility applications, the International Telecommunication Union (ITU) studied how to deliver higher data rates without causing harmful interference into other authorized radio services. Eventually, the ITU's World Radiocommunication Conferences (WRCs) in 2015 and 2019 agreed on regulatory and technical conditions for providing ESIMs in globally allocated Ka-band uplinks and downlinks. At the upcoming WRC in late 2023, the ITU will consider extending ESIMs to spectrum allocations utilized for non-geostationary FSS systems.

D2D Market: Size and Growth

To understand the nascent D2D market, one must first consider that it exists at the convergence of three established markets, each seeking to expand their customer base (see Figure 1). These wireless markets are all driven by the demand for ubiquitous connectivity, as well as the drive to lower costs through beneficial synergies from network and enterprise convergence (see downward and inward arrows, Figure 1). Convergence benefits include:

- Terrestrial MNOs will attract new customers and expand connectivity to existing customers when customers are roaming out of range of terrestrial cellular signals.
- Satellite operators will expand their potential user base by allowing customers with consumer-grade cell phones to use their services when they venture out of cellular coverage areas.
- IoT application providers will expand their network reach by using a range of D2D providers instead of relying upon proprietary networks.

Three Key Market Drivers. Three key drivers could advance the state of play for the D2D market.

Demand for Ubiquitous Connectivity. The Fourth Industrial Revolution[‡‡] is described as "billions of people connected by mobile devices, with unprecedented processing power, storage capacity, and access to knowledge." Wireless subscribers and enterprises are demanding seamless connectivity everywhere, across devices, sensors, infrastructure, and phones. This everywhere connectivity will be multiplied by other emerging technology breakthroughs in fields such as artificial intelligence, robotics, the IoT, and autonomous vehicles.

Since 2010, the ITU/UNESCO Broadband Commission for Sustainable Development has engaged in high-level advocacy to promote broadband in developing countries and underserved communities through partnerships among the private sector, government, civil society, and international organizations.[9] The U.S. government is also striving to close the digital divide. The Infrastructure Investment and Jobs Act, passed in 2021, dedicated $65 billion for broadband funding and the Rural Digital Opportunity Fund will disburse up to $20.4 billion over 10 years to bring fixed broadband and voice service to millions of unserved homes and businesses in rural America.[10] Notwithstanding these initiatives, it is too soon to tell if D2D service providers will be able to

[‡‡]At the World Economic Forum, Klaus Schwab defined four industrial revolutions and how they have fundamentally altered the way society lives, works, and relates to one another.

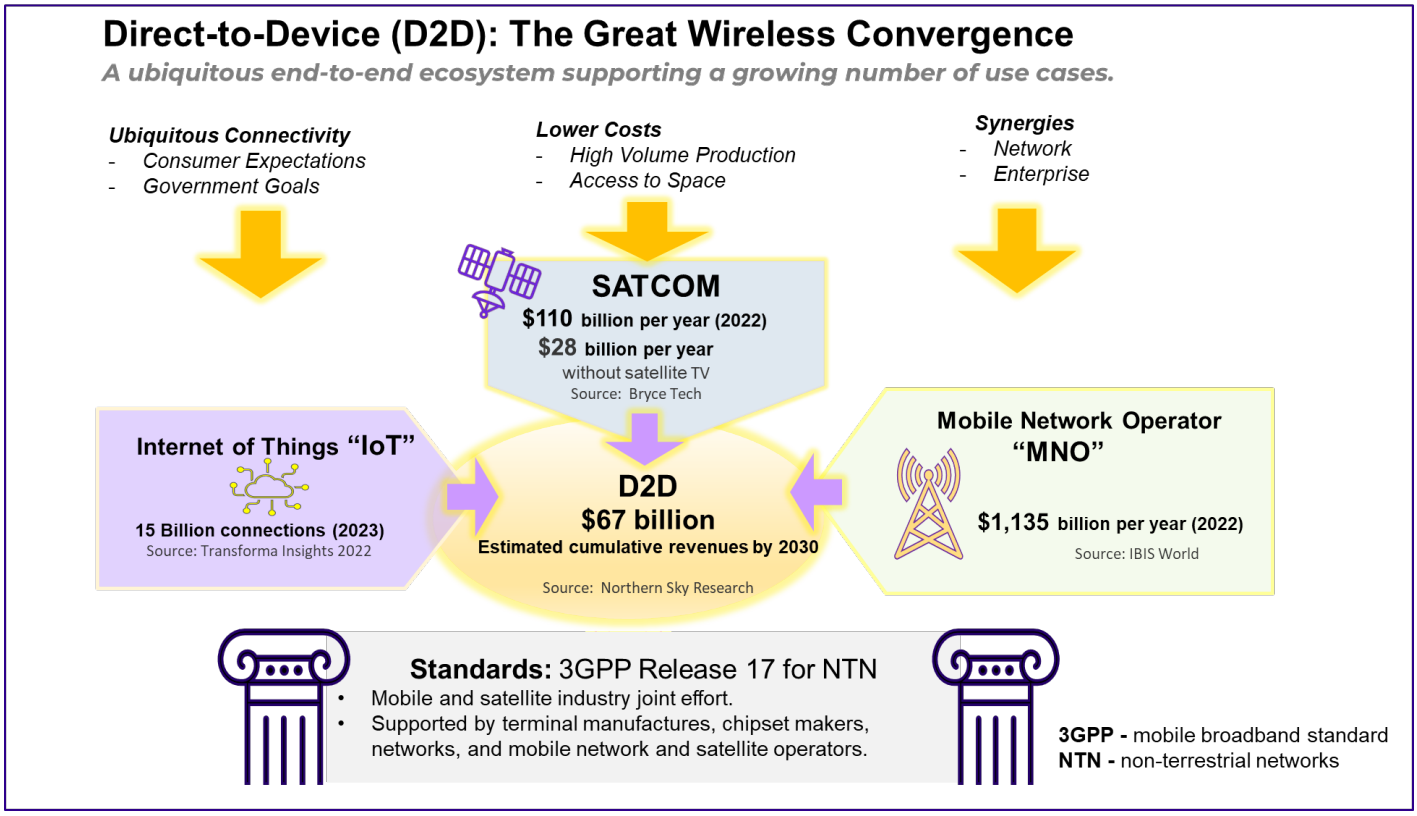

Figure 1: The Great Wireless Convergence. *Ubiquitous connectivity demand, lower costs for launch and satellite production, and increased synergies from network convergence and enterprise efficiencies are all key market drivers for D2D. D2D capabilities exist at the nexus of satellite communication technology, established networks of MNO customers, and the large and growing IoT market. The foundation for wireless networks, including IoT, satcom, MNOs, and D2D, is supported by international industry consortium standards, known as 3rd Generation Partnership Project (3GPP). 3GPP has been working on non-terrestrial networks (NTN) standardization, most recently with 3GPP Release 17.*

provide broadband speeds in populated areas.[§§] Elon Musk, in commenting on Starlink's ability to provide higher speed connectivity tweeted that "total bandwidth" within a Starlink cell would be "divided among all phones."[11] Therefore, speeds would be reduced significantly for those users, in high population density areas, that share the same spot beams.

Lower Costs. Space is a competitive commercial environment with declining launch and satellite manufacturing costs. Compare, for example, the 1981 Space Shuttle cost of $85,216 to the 2020 Falcon 9 cost of $1,891 per kilogram to low Earth orbit. There is also speculation that SpaceX's Starship, the largest rocket ever flown, could push costs even lower.[12, 13, 14,15] This degree of steep price decline can be considered a disruptive market force which may attract new customers.

In addition to lower launch costs, the space industry has experienced a 90 percent drop in the manufacturing cost per Gbps of capacity. Between 2013 and 2021, the overall throughput per kilogram of satellite weight increased six times due primarily to the number of deployed High Throughput Satellites (HTS) and Very High Throughput Satellites (VHTS) satellites.[16] Adding to lower manufacturing costs, the satellite industry has adopted high volume production techniques to produce satellites faster and cheaper, particularly for very large constellations.[17]

[§§]On December 8, 2022, Elon Musk tweeted about Starlink's upcoming D2D service in partnership with T-Mobile, and qualified future speeds by noting that earlier estimates of speeds were total bandwidth within a cell, "so bandwidth would be divided among all phones." Musk added that Starlink's D2D service "will be great for text messages, voice calls and low res pics."

Network and Enterprise Synergies. Metcalfe's Law, coined by Robert Metcalfe, inventor of Ethernet, states that "the value of a network is proportional to the square of the number of connected users. As the physical cost of the network grows linearly, its value grows exponentially."[18] Economists refer to this as "network effects," referring to a positive benefit that a consumer receives from a good when the number of consumers of the good increases. Put simply, networks become more valuable as more users join. Both satellite operators and MNOs could view satellite D2D as a net positive, or "increasing the size of the pie," because combining terrestrial and satellite communication networks could increase the overall value of both.

In addition to network synergies, complementary joint efforts can also offer cost synergies for both the MNO and the satellite enterprises:

- MNOs can avoid costs associated with cell site deployment and network integration for underserved and remote areas and instead offer satellite-based D2D.

- Satellite providers can do more with less and rely upon the MNO's existing customer relationship management tools and avoid service provisioning overhead expenses.

Market Convergence. Northern Sky Research predicts that new satellite D2D services will attract "potentially 386 million users by 2030 and deliver as much as $66.8 billion in 10-year cumulative revenues for the satellite industry."[19] This future market lies at the convergence of satellite services, terrestrial cellular services (the MNO market), and IoT services.

Satellite Services. During 2022, the satellite communication services market generated approximately $110 billion in revenues, but decreased by 4.2 percent compared to the previous year primarily due to the drop in satellite TV revenues.[20] Without the satellite TV market, the satellite communications market is only $28 billion per year. Satellite service providers such as Iridium, Globalstar, OneWeb and SpaceX's Starlink, are seeking to broadly expand their slim piece of the connectivity pie to general consumers who seek ubiquitous connectivity for their existing mainstream devices—such as smartphones, tablets, laptops, and vehicles.

Looking to the future, Iridium, a leading provider of satellite-based IoT services, provides a glimpse as to where the satellite services market may turn for higher growth. Iridium is counting on the "increasing demand for automated data collection processes from mobile and remote assets operating outside the coverage of terrestrial wire line and wireless networks, as well as the continued need to integrate the operation of such assets into enterprise management and information technology systems."[21] These IoT opportunities are emerging across a range of vertical markets—such as mining, construction, oil and gas, utilities, heavy industry, maritime, forestry and transport companies as well as the military, public safety, and disaster relief agencies. And while some of these markets are already part of Iridium's existing strategy to grow machine-to-machine "M2M" data connections, the D2D architecture could offer lower device and connectivity costs.

Terrestrial Cellular Services. The $115 billion satcom market is expected to converge with the much larger global terrestrial wireless telecommunications industry which is expected to generate $1.135 trillion during 2023.[22] In this sense, satcom could become a small fish in a much bigger pond—a veritable ocean—with expanded growth opportunities.

Strategic partnerships between terrestrial based MNOs and satellite providers will enable 5G networks to extend their reach to rural or remote communities. Predicting specific use cases is difficult. However, most telco experts predict that 5G's impact will be far reaching across many industrial or "vertical markets," ranging from agriculture to manufacturing to health care, and that satellite-enabled D2D will extend the reach of 5G to less dense or remote areas where 5G has proven to be less practical.[***] In the future, D2D services could enable emergency and disaster relief communication, support humanitarian missions, and

[***]5G's millimeter wave frequencies (24 GHz to 40 GHz) promised to unlock new bands of spectrum to allow for lower latencies and greater data rates. But the laws of physics constrain higher frequencies from travelling far. And while dense urban areas might find these higher and less resilient frequencies useful, they become less practical for sprawling suburbs and remote areas.

provide critical communications to the warfighter in conflict areas.

IoT Services. The IoT market comprises a range of customer segments—including smart city applications, smart home systems, automotive, smart finance, consumer, healthcare, and industrial applications. New innovative IoT solutions are emerging at a rapid pace and devices are becoming more capable, faster, smaller and less costly, which spurs additional demand for a range of consumer and vertical market applications.[23] One report shows IoT-connected devices worldwide will grow from over 10 billion connections in 2021 to almost 30 billion IoT devices by 2030.[24] However, reliable revenue estimations from sales of IoT products and services were not well documented. Instead, the number of IoT devices provides a helpful, and perhaps predictive, perspective on the IoT market growth trend (see Figure 2).

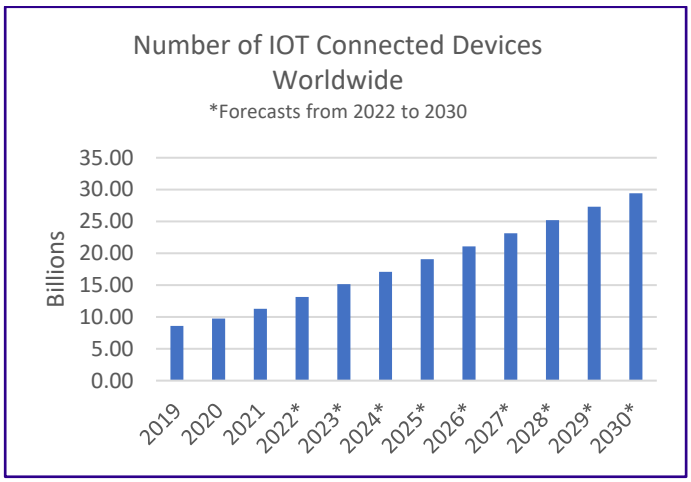

Figure 2: Number of IOT Connected Devices Worldwide. *Forecasts from 2022 to 2030. (Source: Transforma Insights 2022)*

Legacy satellite operators with custom IoT hardware solutions may find that their customers prefer to switch to new 3GPP Release 17-compliant IoT solutions which can connect to cell towers or satellites operating in covered frequency bands. To this end, emerging IoT companies that make use of the 3GPP Release 17 standard could displace older and less versatile IoT service models.[25] Strategic and mutually beneficial mergers may also occur. For instance, SpaceX's recent acquisition of Swarm Technologies, will allow Starlink's D2D service to support Swarm's existing IoT customers involved in industrial market sectors such as aviation, maritime, trucking, energy, and mining.[26]

The Evolution of Terrestrial and Satellite Networks

The emergence of D2D is an inevitable result of several decades of terrestrial and satellite network evolution, starting with satellite backhaul support of the 2G and 3G cellular industry in remote locations and now gradually expanding to non-terrestrial networks (NTN), which can be integrated as part of 5G.

Evolving to a Unified Communications Frontier. Future 6G will culminate in a more unified network of networks (see Figure 3). Mobile wireless standards have evolved from first generation (1G) analog voice to fifth generation (5G) standards. Today's 5G networks provide the building blocks for satellite-terrestrial integration. According to the Global Satellite Operators Association, future 6G networks will build on 5G standards to unify terrestrial and satellite networks "with inbuilt ubiquity, continuity, scalability & resilience."[27]

Foundational Standards for Integrating Non-Terrestrial Networks (NTN). There are many complexities associated with the operation of integrated satellite and terrestrial network infrastructure in the context of 5G communications and standards to enable service continuity, ubiquity, and scalability.[28] 3rd Generation Partnership Project (3GPP) is the international industry consortium responsible for defining technical specifications for mobile wireless networks. 3GPP has been working on NTN standardization for several years, most recently with 3GPP Release 17. This global standard will introduce new network topologies into the 3GPP specifications, including LEO, MEO, and GSO satellites. High altitude platform stations (HAPS) could also be part of the solution to address connectivity gaps, as HAPS operators have already demonstrated 4G and 5G connectivity up to 200 megabits per second (Mbps) from high altitude vehicles directly to unmodified user handsets.[29]

Why is this NTN standard significant? 3GPP Release 17 for NTN is a joint effort between mobile and satellite

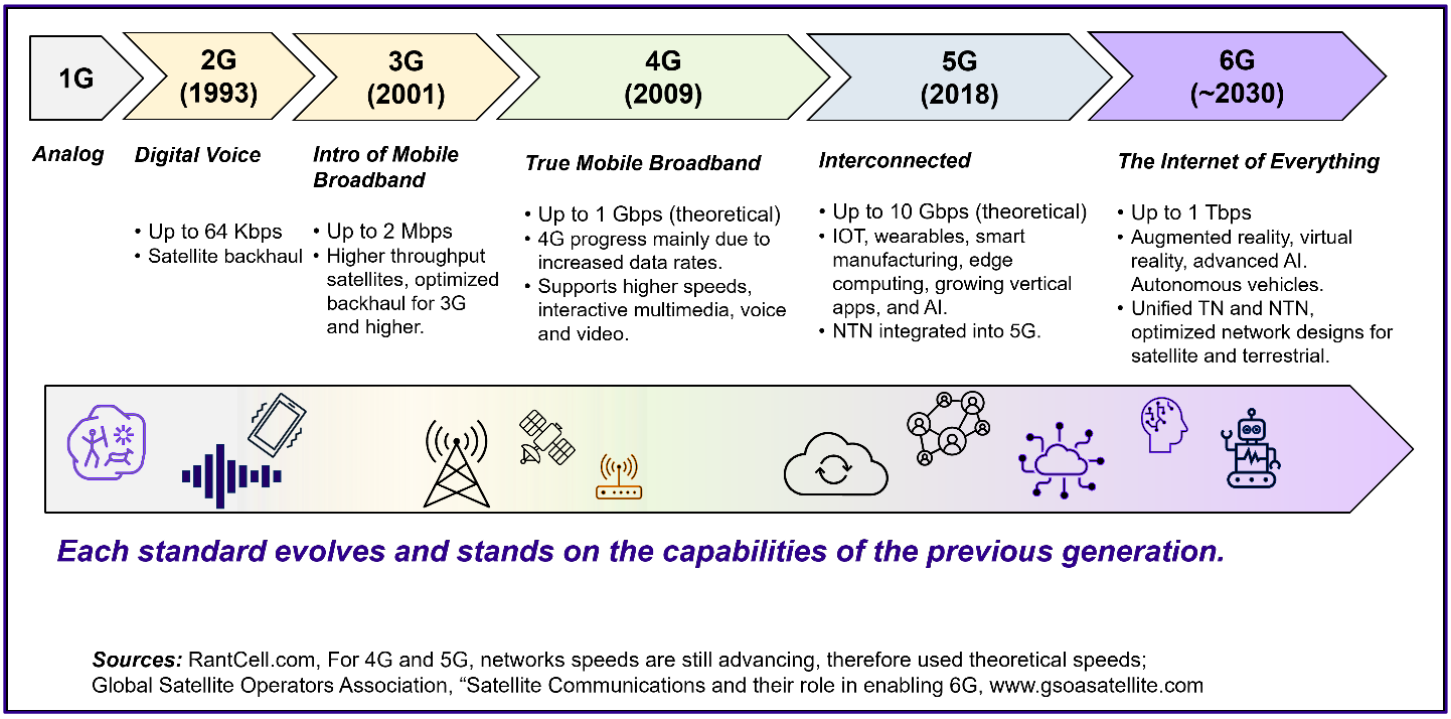

Figure 3: Terrestrial and Satellite Network Evolution. *Convergence has occurred gradually over 30 years and several generations.*

industries and is supported by a larger ecosystem of wireless stakeholders, including terminal manufacturers, chipset makers, network equipment manufacturers, and mobile network and satellite operators. In short, 3GPP Release 17 is the foundation for future NTN products and services. The Global Satellite Operators Association underscores the importance of these standards for future 6G networks, "Building on the Internet of Things conceived around 4G, and further expanded in 5G to support NTN, 6G networks will link sensors everywhere to create the Internet of Everything. Communications satellites in a variety of orbits are particularly well-suited for distributing critical information in 6G networks over wide areas."[30]

Technical Challenges

D2D service providers face several technical challenges. However, for low throughput applications such as SOS services, two-way messaging and voice, technical challenges are already being met with proven technology demonstrations from Lynk Global and AST SpaceMobile, and commercially available services such as Apple's *Emergency SOS* and Bullitt's phone app for emergency messaging in the United Kingdom. Despite these advances, connecting, maintaining, and scaling to deliver quality connections over D2D networks remains technically complex.

Connecting, Overcoming the Doppler Shift, MNO Compatibility. Connecting a consumer-grade cell phone to a fast-flying LEO satellite or a very distant GSO satellite is no small feat. First an operator must conduct a link analysis to account for the difference between the transmit power and the receiver power. If the MNO base station and the cell phone are within a few hundred meters of each other, or if the mobile station is not moving, the Doppler shift due to movement, is inconsequential. However, for communicating between a LEO satellite travelling at 17,500 miles per hour at 400 kilometers altitude, both relative speed and distance contribute to closing the link between the mobile device and the terrestrial base station. Research, tests, and demonstrations are currently underway to explore how existing cell phones (with no physical modifications) can connect directly to satellites. Lynk Global's patented technology, for instance, has successfully demonstrated how to advance or retard the transmission and send bursts of radio frequency (RF) signals to account for propagation

delays.[31] AST SpaceMobile has also provided successful frequency compensation techniques to link to a consumer-grade cell phone.

The MNO must also provide network software to ensure that the phone is "tricked" into accepting the time delay from an extended range connection. Despite the technical complexity, both Lynk and AST SpaceMobile have conducted successful D2D demonstrations on MNO networks. Finally, a cell phone connecting to a satellite would need to operate at higher power levels to close the link with a satellite. This could impact the cell phone's battery life. AST SpaceMobile claimed "only a negligible difference in battery life" when connecting to a LEO satellite, although longer term field studies are needed to observe how battery life is affected.[32]

Capabilities and Quality of Service (QoS). Consumer-grade cell phones are not optimized for satellite connectivity as "off-the-shelf" cell phones with built-in antennas are designed to connect to stationary terrestrial towers. For this reason, maintaining the connection for voice calls or broadband can be challenging. Even with a terrestrial connection, delivering video to mobile devices requires a balance to achieve high quality coupled with manageable file sizes.[33] Initially, D2D services will focus on emergency messaging, such as Apple's *Emergency SOS* service, introduced during November 2022. A D2D service provider could potentially offer any one or combination of the following capabilities listed in approximate increasing order of throughput requirements:

- **Emergency messaging.** Smartphone automatically calls the local emergency number and shares location information with emergency services using satellite networks. Examples: Apple iPhone 14 "built in" capability in partnership with Globalstar. In China, HuaWei Technologies is partnering with Beidou global positioning system to offer similar services.

- **Text messaging.** Text messaging or short message service "SMS" is a text-only format that appears to be the baseline service that all existing and emerging D2D providers are targeting.

- **Voice.** D2D voice demands higher data rates than text messaging. In April 2023, AST SpaceMobile announced the first voice call with a standard smartphone using its BlueWalker 3 test satellite in LEO.[34]

- **IoT.** A network of physical assets or "things" that are embedded with sensors, software, and tracking tags for the purpose of connecting and exchanging data with other devices and systems over the internet. A subset of IoT, NarrowBand-IoT, relies upon a standards-based low power technology for data connectivity.[†††,35]

- **Video.** Uploading and sending videos clearly marks a significant leap in throughput ability demanding between 800 to 1200 kbps.

- **Broadband.** As the D2D market matures, service providers may find ways to improve both speed and performance. Although, most D2D providers are not expecting to reach these broadband speeds, as currently defined by the FCC, at least during the early years of D2D service.[‡‡‡]

Throughput. Scaling the solution to serve several customers in unserved areas is yet another challenge. For operators looking to deliver continuous voice or broadband service to cell phones, the task becomes even more difficult. As an indirect comparison (not D2D services), a network intelligence company observed that Starlink's slower downlink data rates are directly related to an increasing number of users within an individual satellite spot beam. In other words, satellite throughput sharing slows down data rates to individual Starlink terminals.[36]

[†††]NB-IoT (3GPP Release 14) uplink rates have increased to 150 kbps, enabling advanced positioning technologies for Observed Time Difference of Arrival "OTDOA" and Enhanced Cell ID "E-CID," to improve location accuracy.
[‡‡‡]FCC-defined broadband speeds are 25 Mbps download and at least 3 Mbps upload. Members of Congress have called on FCC and other federal officials to update the "broadband" definition to refer to higher speeds.

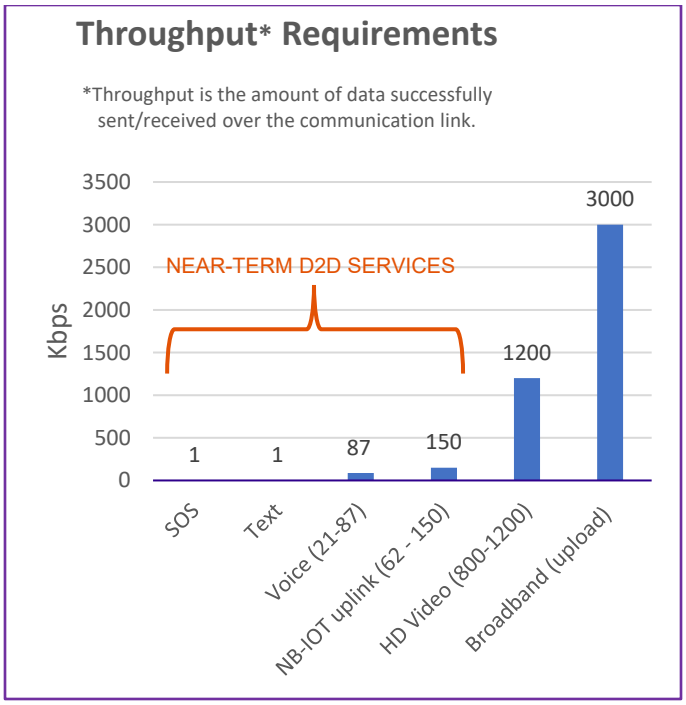

Figure 4: Connectivity services throughput requirements for a range of wireless data communications links.[37]

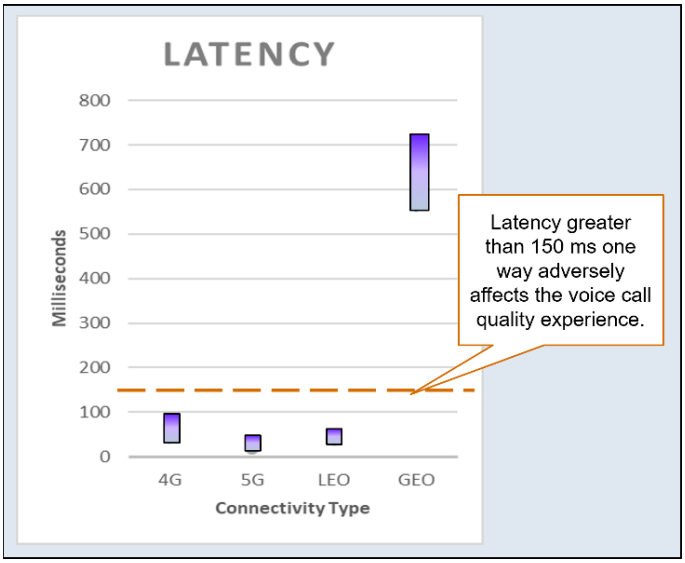

Figure 5: Latency. *Latency based upon widely stated estimates.*

Latency. Latency, measured in milliseconds (ms), is the time for a data packet to travel from one designated point to another. Latency is often an indicator of data performance, particularly for voice and broadband quality of service (QoS).38 Terrestrial cellular networks have a lower latency compared to satellite systems since a satellite's altitude and roundtrip signal path increases the total propagation delay.[§§§] Terrestrial 4G networks reduce latencies to around 30 ms to 70 ms approaching the theoretical 4G latency of just 10ms. Terrestrial 5G networks are somewhere between 5 ms and 20 ms, with the 3GPP goal to push the latency down to 1 ms.

Latency concerns could be partially driving the apparent market enthusiasm for LEO constellations, orbiting at 400 to 1500 km above sea level, versus higher altitude GSO satellites which typically orbit around 35,800 km (see Figure 5). LEO latency is currently approximately 30 to 40 ms while GSO latency is approximately 600 ms. On a practical level, end user applications drive the specific solution. For many applications outside high-speed gaming or financial trades, a few hundred milliseconds will not matter for text messages or emergency messaging. However, for voice calls or faster broadband speeds, higher latency will impact QoS.

Business and Regulatory Issues

To grow and gain market traction, D2D service providers must address a range of business and regulatory issues. From a U.S. regulatory perspective, the FCC has taken a forward-leaning posture to facilitate the integration of satellite and terrestrial networks by launching its rulemaking proceeding ("Supplemental Coverage from Space") and issuing experimental authorizations to test D2D services. Still, there are many regulatory hurdles to tackle, both domestically and internationally.

Barriers to Entry. For simple SOS emergency messaging (one-way) or low bandwidth two-way messaging, companies such as Apple, Lynk Global, and AST SpaceMobile have concluded several successful demonstrations. While connecting, maintaining, and scaling D2D is not insurmountable, the technical complexity presents an advantage for more established D2D providers and a potential barrier to entry to unproven new entrants. Existing D2D market participants have pursued patents to protect their intellectual property (IP). And while patent protection may not prevent market access by new entrants, it is a well-known path to restrict

[§§§]The signal must go from cell phone to satellite, from satellite to Earth station or gateway (possibly with a satellite crosslink hop) and then interact with terrestrial networks and make the return trip.

or delay market entry. Looking at existing D2D stakeholders, for example:

- Lynk Global holds eight patents going back to 2018 that address various complexities involving orbital terrestrial communications.[39]
- AST SpaceMobile has secured 15 United States patents.[40]

International Telecommunication Union (ITU) Radio Regulations

Since its founding in 1865, the ITU has worked to encourage international cooperation among countries, the commercial sector, and other stakeholders to achieve practical solutions for integrating new telecommunication technologies while ensuring efficient and responsible use of spectrum. Every four years, the ITU convenes a World Radiocommunication Conference to address technical and regulatory issues to introduce emerging communications technologies with international impact while protecting the operations of incumbent providers from harmful interference. The Conference results in amendments to the *Radio Regulations*, a four-volume 2000-page treaty on use of radiofrequency spectrum and associated orbital resources. The Radio Regulations contain an International Table of Frequency Allocations which provides entries indicating frequency bands are to be used for particular radio services under specified conditions. Member States are to assign frequencies (usually via licensing) in their countries in accordance with the Table of Frequency Allocations to avoid causing harmful interference to services and duly authorized radio stations in other countries that operate in conformity with the Radio Regulations.

D2D Spectrum Regulatory Risk. Regulatory issues remain a formidable challenge for D2D entrants, despite the FCC's enthusiasm for D2D as a new service which could advance important policy and social goals related to universal connectivity. To understand the regulatory risk, it is essential to differentiate between those services that seek to provide D2D utilizing their MNO partner's licensed **terrestrial** mobile spectrum transmitting from space (an uncertain regulatory environment), such as Lynk Global, AST Space Mobile, and Starlink, from those providers who seek to offer D2D services utilizing spectrum allocated for **space services,** such as Iridium and Omnispace (a more established regulatory environment). The regulatory risks are markedly different for these two cases of D2D services and could impact their ability to meet their business plans and schedules.

In general, ambiguous government policies can create regulatory risks and discourage commercial companies from making significant investment decisions. However, in the case of the nascent D2D market, at least three commercial D2D providers using licensed terrestrial mobile spectrum proactively invested in this uncertain regulatory environment. One key question: Is the perceived early market advantage for terrestrial spectrum D2D providers worth the upfront capital risk as spectrum policies and regulations are still waiting to be addressed at the ITU and most domestic administrations of other nations? And even within the U.S., the regulatory regime for D2D is not yet finalized.

Terrestrial Wireless Spectrum for Space Applications. The domestic and international regulations pertaining to spectrum use do not presently accommodate the use of frequency bands allocated for terrestrial services (including mobile spectrum supporting wireless services, such as 5G) to be delivered by space stations (satellites). Indeed, the FCC observed in its SCS Notice of Proposed Rulemaking (NPRM) that "[a] proposed SCS system involving space and earth station transmissions on spectrum bands allocated only for fixed and/or mobile service would require that the U.S. Table [of Frequency Allocations] be modified to enable Earth-to-space and space-to-Earth operations in the relevant bands."[41] In addition, technical studies and standards for equipment performance and operational conditions have not yet been advanced, deliberated, and accepted to demonstrate that they can be operated in these frequencies in a manner that will avoid harmful interference to incumbent (or future) systems that have rights to protection due to their regulatory status. The processes for developing national—and international—spectrum allocations, regulations, and standards are usually multi-year endeavors typically pursued as a necessary effort for launching an innovative new spectrum-based service that is not yet permissible under the existing regulatory framework (see sidebar: International Telecommunication Union Radio Regulations).

International Recognition of D2D. Transmitting MNO terrestrial spectrum from space is also a nonconforming use under the current international regulatory regime for spectrum use, the ITU's Radio Regulations. Terrestrial D2D proponents have not yet made the case in front of the ITU to demonstrate that D2D utilizing spectrum allocated to terrestrial services could safely operate from space without negative impact to allocated services. Moreover, review of the regulatory framework to enable terrestrial D2D, including allocation changes to recognize use of terrestrial mobile spectrum from space, is not included on the agenda of the ITU's upcoming World Radiocommunication Conference (WRC-23) at the end of 2023. The next opportunity to amend the Radio Regulations will be at the next WRC in 2027.

One of WRC-23's major tasks is to assemble a proposed agenda for the next World Radio Conference, WRC-27. Some ITU Member States are planning to propose an item for the agenda to consider making additional MSS spectrum allocations to increase connectivity services, including D2D utilizing satellite spectrum.[42] Perhaps proposals will also surface at WRC-23 to include an item on the WRC-27 agenda to address D2D utilizing terrestrial spectrum.[****]

Nonconforming Operations and No. 4.4 of the Radio Regulations. Until such time as the Radio Regulations provide regulatory status for D2D utilizing spectrum in an appropriate allocation, nations authorizing the service are responsible to ensure that such operations avoid causing harmful interference to authorized radio stations of other States. Nonconforming operations licensed by national administrations are subject to No. 4.4 of the Radio Regulations. This regulatory provision is typically reserved for experimental, temporary, or emergency operations, and is not generally intended to support a permanent or commercial service. No. 4.4 operations must not cause harmful interference and must have the capability to immediately shut down in the event of causing harmful interference. Likewise, these non-conforming operations receive no protection from harmful interference—including from future stations. The topic of appropriate (or inappropriate) use of No. 4.4, including its application to some D2D services, is likely to be addressed at WRC-23. Concerns about the possible misuse of No. 4.4 were expressed by multiple Member States and by the ITU's Radio Regulations Board at its Conference Preparatory Meeting (CPM) during Spring 2023, summarized in *Report of the CPM to the WRC-23*, which will be taken under consideration per WRC-23's Agenda.[43]

FCC Rulemaking on "Single Network Future: Supplemental Coverage from Space." The FCC's March 17, 2023, Notice of Proposed Rulemaking (NPRM) on "Single Network Future: Supplemental Coverage from Space" is intended to facilitate the integration of satellite and terrestrial networks with a new regulatory framework referred to as "SCS." The main goal is to expand coverage to terrestrial licensee subscribers in remote and underserved areas utilizing cellular spectrum from satellites.[44] The Rulemaking applies to D2D transmissions via satellite to terrestrial devices on spectrum licensed for terrestrial wireless networks. The Commission notes that there are other models under which D2D can be provided, including utilizing spectrum allocated to the Mobile-Satellite Service (MSS), and that these models are distinguishable from terrestrial spectrum-driven D2D and "may not raise the same novel legal and technical complexities as providing supplemental coverage from space using terrestrial spectrum."[45]

A few years prior to the NPRM, the Commission set the stage for D2D services, or Supplemental Coverage from Space (SCS), by granting experimental licenses to:

- Lynk Global to test communications between satellites and "mobile station locations" in the 800 MHz band.
- AST SpaceMobile for Earth stations to communicate with a satellite licensed by Papua New Guinea.

Later during 2022, the Commission granted Lynk Global authority to operate a non-geostationary satellite orbit (NGSO) system, noting that it was "in the public interest to begin making Lynk's services accessible." The order is contingent upon Lynk Global obtaining appropriate approvals in the relevant jurisdictions outside the U.S. and

****The formal deadline for submission of proposals by ITU Member States to the 2023 World Radio Conference is October 30, 2023. (https://www.itu.int/wrc-23/documents/).

the completion of coordination with other operators. Even with such domestic approval, Lynk Global's operations in other countries are limited to a noninterference/non-protected basis due to its nonconformity with the ITU's Radio Regulations (per No. 4.4), and a myriad of technical and coordination conditions. Although the FCC conditional authorization was a big step forward for Lynk Global, the Order did not authorize its use of UHF (terrestrial mobile) links to provide D2D service in the United States. The FCC noted that its decision was "was without prejudice to action on any applications to provide similar service in the United States."[46]

Six months later, the FCC released its SCS NPRM—asserting the value of network convergence while incentivizing creative partnerships between terrestrial networks and space operators; encouraging high quality of service for 4G and 5G terrestrial networks; and protecting spectrum usage rights. Chairwoman Rosenworcel also emphasized future benefits:

> By providing clear rules, I believe we can kick start more innovation in the space economy while also expanding wireless coverage in remote, unserved, and underserved areas. We can make mobile dead zones a thing of the past. But even better, we have an opportunity to bring our spectrum policies into the future and move past the binary choices between mobile spectrum on the one hand or satellite spectrum on the other. That means we can reshape the airwave access debates of old and develop new ways to get more out of our spectrum resources.[47]

With regard to reuse of terrestrial mobile spectrum from space, the FCC confined its initial proposal to spectrum and locations where *only a single terrestrial entity* holds, either directly or indirectly, all co-channel licenses for the relevant frequencies in a given geographically independent area.[48] This requirement stems from the need to minimize the possibility of harmful interference between MNOs serving adjacent markets, acknowledging the "differences in interference metrics and mechanics between satellite and terrestrial-based networks, as well as the increased potential for harmful interference caused by satellite signals that may have a larger footprint into an adjacent service area that a terrestrial network's limited operations near service area borders." This geography constraint can introduce a significant market risk for those D2D operators who operate in diverse markets such as the United States with many MNOs working across a diverse range of frequencies often secured through spectrum auctions sold off in various geographical area units. However, it is not necessarily a limiting factor in some geographies where there is only a single terrestrial licensee, such as might be the case of a small island state (see Section VIII. Market Risks).

Also, as part of the NPRM, the FCC limited the SCS framework to non-geostationary satellite orbit (NGSO) operators because such satellite operators "are likely to rapidly deploy these space stations after receiving any needed modification to their existing authorizations." While proposing this initial step, for NGSOs, the FCC indicated that this is the most efficient path for enabling SCS in the near-term as they seek comment on potential expansion of the SCS framework.[49]

As expected, some concerns regarding the FCC's proposed SCS framework NPRM have been expressed—particularly from incumbent MSS operators. DISH Network Corporation, EchoStar Global, Hughes Network Systems, and EchoStar Mobile Limited in a consolidated response urged the FCC to take "a cautious, incremental approach to adopting rules on the use of specified terrestrial spectrum to provide SCS."[50] A more strongly opposing view to the FCC's new regulatory framework comes from Omnispace LLC, an NGSO MSS operator in S-Band spectrum included in 3GPP Release 17. Omnispace asserts that the Commission's SCS framework will "introduce co-channel interference in contravention of international treaty obligations," and that the FCC "neglected a myriad of sharing and interference issues, and reneges on the U.S.'s commitment to the principles of the treaty that sets forth the allocation decisions made at World Radiocommunication Conferences (WRCs)—the ITU Radio Regulations."[51] Omnispace further asserts, in response to an FCC Public Notice about Starlink's proposed D2D operation utilizing MNO T-Mobile's PCS G Block spectrum, that this service will cause harmful interference to Omnispace's satellite system which is operating in compliance with the Radio Regulations and domestic authorizations and, therefore, is entitled to

international recognition and protection from harmful interference.[52] Similar concerns were shared by Canadian MSS provider TerreStar Solutions, Inc. and DISH Networks. Concerns over potential harmful interference to terrestrial spectrum services were also raised by AT&T Services and the Rural Wireless Association. SpaceX and T-Mobile submitted responses to the Commission, rebutting these claims and concerns.

Another operator who plans to use GSO satellites to offer D2D services, Skylo Technologies, urged the Commission to remain neutral regarding the space architectures for SCS services and allow operators to offer a system "that will best serve customers."[53] Other GSO operators also emphasized the need for a technology-neutral approach to encourage innovation and flexibility, as the existing NPRM only addresses NGSOs.

The HAPS Alliance, an industry-led advocacy group of fixed-wing aircraft, balloons, and airships designed to operate in the Earth's stratosphere, also responded to the FCC's NPRM to emphasize that the SCS framework "not prohibit or impair the use of HAPS as a complementary layer for standard direct-to-handset radio-frequency bands."[54]

Clearly, vested equities from GSO, MEO, and HAPS operators will be watching to ensure that the FCC's evolving SCS framework protects incumbent operators.

D2D Providers – Competitive Landscape

A range of companies, large and small, are actively designing and introducing D2D services. Other providers are in various phases of research, demonstration, and early market introduction. New and emerging satellite D2D architectures are enabling game changing connectivity with consumer grade smartphones through a range of startups, existing satellite companies, and MNOs. To date, D2D providers fall into two categories: Terrestrial spectrum-centric versus satellite spectrum-centric. Each category has its unique strengths and weaknesses. It is too early to predict how the addressable market will adopt each.

Satellites Using Terrestrial Spectrum, Connecting to Unmodified Cell Phones. This D2D solution starts with MNO partnerships and uses terrestrial cellular spectrum exclusively controlled by the MNO and an **unmodified** mobile device, typically a cell phone but perhaps a cellular-enabled tablet, laptop, or IoT device. Leveraging off-the-shelf (OTS) smartphones enables an early "go-to-market" advantage. Phone connectivity capabilities can work as a communications relay station (sometimes casually referred to as "cell towers in the sky") to augment terrestrial-based networks or work as a back-up capability if terrestrial systems fail. To fill in dead zones, the satellite systems need to emulate cell towers by using software stacks used in terrestrial cell networks to "trick the phone" into thinking that it is communicating with an MNO cell tower. This D2D method involves somewhat complex Doppler shift technology. However, demonstrations by both Lynk Global and AST SpaceMobile have already proven that reliable connections can be made.[55]

Strengths

- **First mover advantage.** On a global basis, there are approximately 6.92 billion unmodified cell phones. Users will not need to buy a new phone or adapt an existing mobile device. Instead, based upon MNO agreements, D2D service providers with operating satellites can provide immediate service (upon regulatory approval) to MNO subscribers using any standard unmodified mobile phone. MNO subscribers will have the flexibility to "turn on" coverage based upon need. AST SpaceMobile, for instance, allows a "day pass" as well as a monthly "add on" for supplemental service to existing cellular plan.[56]

- **FCC's support to facilitate the integration of satellite and terrestrial networks.** The FCC's pending Notice of Proposed Rulemaking "Single Network Future: Supplemental Coverage from Space" proposes a new regulatory framework whereby satellite operators collaborating with terrestrial service providers would be able to obtain Commission authorization to operate space stations on currently licensed, flexible-use spectrum allocated to terrestrial

services, thus expanding coverage to the terrestrial licensee's subscribers, especially in remote, unserved, and underserved areas.[57]

Weaknesses

- **High Capital Cost of Space Network.** New capital-intensive constellations of satellites are needed to provide service to existing unmodified cell phones.

- **Spectrum uncertainty.** MNO terrestrial frequencies are not allocated or licensed for satellite usage. AST SpaceMobile, Lynk, and Starlink would operate using MNO partners' existing terrestrial licenses, but additional approvals will be needed, such as spectrum lease arrangements and special rule waivers, in addition to possible new domestic and international regulatory requirements. D2D providers must ensure that they can operate without causing interference to other stations, which may be difficult in spectrum blocks that were auctioned to different MNOs in smaller geographical areas. In addition, without regulatory status, these D2D links may not receive protection from harmful interference from other existing or future stations.

Satellites Using Terrestrial Spectrum, Connecting to Unmodified Cell Phones

Company, Status, and Coverage	User Device	LEO	GEO	D2D Services and Description
AST SpaceMobile (USA) **Status:** demo phase **Coverage:** Regional/Global, 21 countries in Europe, Asia, and Africa.	Unmodified mobile devices			**Services:** SOS, two-way text, voice, and broadband. **Description:** Working with several MNOs. BlueWalker 3 satellite (BW3) in LEO (Nov 2022). During June 2023, AST announced >10 Mbps download speeds during testing. BW3's phased array antenna (693 ft^2) forms and steers communication beams into coverage cells. However, the large surface area poses an increased space debris risk.
Lynk Global (USA) **Status:** demo phase **Coverage:** three operational satellites, limited coverage during early phase of deployment.	Unmodified mobile devices			**Services:** SOS, two-way text and IOT. Intends to expand to voice and mobile broadband services. **Description:** Demonstrated service on seven continents. More than 30 MNO service contracts covering over 50 countries.
SpaceX – Starlink (USA) and **T-Mobile** (USA) **Status:** testing during 2023, possible service launch mid-2024. **Coverage:** (+58° to –58°), contiguous US, Hawaii, Puerto Rico, Southeast Alaska, Kodiak, and Aleutian Islands.	Unmodified mobile devices			**Services:** SOS, two-way text, IOT, location track, voice and basic web browsing. **Description:** During December 2022, SpaceX filed FCC request to equip 2,016 of its 2nd gen Starlink satellites with a D2D system. Has access to one T-Mobile frequency band for nationwide coverage to support IoT devices equipped with a T-Mobile SIM card. Swarm Technologies acquisition might indicate intent to pursue **both** terrestrial and satellite spectrum, using Swarm's licensed satellite spectrum.

DEMO OR BETA SERVICE PROPOSED OR PENDING

Satellites Using Satellite Spectrum, Connecting to Modified Cell Phones. Satellite operators are collaborating with smartphone providers and chipset manufacturers to adapt consumer-grade cell phones with specialized embedded chipsets to enable satellite connectivity (i.e., smartphones modified to be able to receive D2D from selected MSS frequency bands). In addition to *modified* consumer-grade smartphones, other devices such as tablets, laptops, and even vehicles with dedicated hardware can be adapted to enable satellite D2D connectivity to non-GSO and GSO satellites. The "first to market" example, Apple's version 14 handset, is configured to provide one way SOS messages to the Globalstar constellation which operates 48 LEO orbiting satellites, covering 80 percent of the planet's surface.[58] This emergency service, launched during late 2022, has already saved several lives.[59] In addition to the companies listed below, other satellite service providers, such as EchoStar, Viasat, OneWeb and Kuiper have indicated that they would be interested "in operating satellites that may connect to phones."[60]

Strengths

- **Use existing satellite systems.** D2D capabilities can be integrated into millions of phones, using chipsets designed for the right frequency, at a variety of price points. Modified cell phones can be compatible with a range of MNOs and as a result, avoid the front-end investment costs to launch a new satellite network.††††

- **Greater spectrum certainty.** Today GSO networks and LEO systems are already in global operation in established MSS allocations and licensed to operate in many countries around the world. Thus, these MSS operators have achieved a higher level of regulatory certainty, as compared to those D2D providers using terrestrial spectrum from space.

Weakness

Increased dependence on cell phone manufacturer adaptation and longer time to market. Providers must rely upon phone manufacturers to build and embed new chipsets designed for the right frequency to allow for D2D functionality. Eventually, Qualcomm and other chipset manufacturers (e.g., MediaTek, Apple, Samsung, UNISOC, and Huawei) will "bake in" satellite connectivity into more moderately priced chipsets and phones.[61] However, one might ask, "What if I bet billions on building a satellite network, but the handset manufacturers select a chipset that works with different frequencies than mine?"

Wireless Enabled Accessory Device to Connect Smartphone to Satellite(s)

This type of connection is not an actual D2D service because it is not direct to cell phone. Instead, the cell phone relies upon a secondary device or "fob" to make the connection to the satellite. Earlier during 2023, Motorola debuted the Defy Satellite Link. This hockey puck-sized device connects via Bluetooth wireless to a smartphone, which is enabled by a downloaded app. The smartphone can send SOS emergency messages or send and receive text messages via the Defy Satellite Link when the user is in remote or unserved cell areas. The Defy devices connect to geostationary satellites using the 3GPP NTN open standard "direct-to-device" satellite communications technology.[62]

††††For the Omnispace proposed D2D business model, a new 300-satellite constellation will need to be launched.

Satellites Using Satellite Spectrum, Connecting to Modified Cell Phones

Company, Status, and Coverage	User Device	LEO	GEO	D2D Services and Description
Apple (USA) and **Globalstar** (USA) **Status:** operational, launched Nov. 2022 **Coverage:** US, Canada, Germany, France, Ireland and UK. (–70° to +70°).	SOS feature for iPhone 14			**Services:** One-way emergency messaging when no cellular or Wi-Fi service is available. **Description:** iPhone can send distress signals using Globalstar's satellite network. Apple will spend $450 million, the majority to Globalstar, for satellite network capacity.
Bullitt (UK) Phone App, **Inmarsat** (UK) **Status:** Bullitt Satellite Messenger launched in UK and Europe **Coverage:** almost global (–81° to +81°).	Android Smartphone with Bullit App			**Services:** SOS, two-way messaging, location sharing. **Description:** Offers two Android phones, *Cat S75* for Europe, Middle East, and Africa and *Motorola Defy 2*, for operators across North and South America. Both Android phones connect to Inmarsat GEO satellites. Technology developed by startup Skylo with MediaTek chips.
eSAT Global (USA), **Yahsat** (Saudi Arabia), **Inmarsat** (UK) **Status:** TBD **Coverage:** almost global (–81° to +81°).	TBD			**Services:** Two-way texting, focus on IOT vertical markets. **Description:** Partnership between eSAT Global, Yahsat (3 GEOs) and Inmarsat (14 GEOs) to leverage unused capacity. Working to convince smartphone makers to modify their chipsets to tap into the network.
Iridium (USA), **Qualcomm** (USA) **Status:** launch in select regions starting in 2024 **Coverage:** 100% of planet, including poles.	Future Samsung phones and Android smartphones			**Services:** *Snapdragon Satellite* will start with emergency messaging and later texting, will expand to laptops, tablets, vehicles and IoT. **Description:** Chip maker Qualcomm to connect smartphones with Iridium's LEO constellation. Partnership with Qualcomm could lead to connectivity across different Android-enabled smartphone devices.
Omnispace (USA), **Ligado Networks** (USA) **stc Group** (Saudi Arabia) **Status:** TBD **Coverage:** S. America, Africa, Middle East, Asia Pacific.	TBD			**Services:** Global voice, text, and data. **Description:** Operates an NGSO MEO satellite and two LEO satellites in globally allocated S-band spectrum. Omnispace will combine their licensed S-band MSS spectrum with Ligado's L-band spectrum to provide service in the U.S. Omnispace's two LEO sats are testing prototype 3GPP 5G NTN services in the first phase of a next gen 300 satellite LEO system in 3GPP NTN 2GHz (Band n256).

COMMERCIAL SERVICE DEMO OR BETA SERVICE PROPOSED OR PENDING

Market Risks

Despite the promise of a large and growing market for D2D services, there are risks and uncertainties that could cause the above listed D2D market entrants to potentially fail to meet revenue expectations and goals, at least in the near term. Some market and business risks are discussed below.

Unproven Revenues and Future Value. The market for D2D is still unproven, making both revenue forecasts and market valuation difficult. D2D services could become a valuable non-revenue-generating item. In other words, a D2D service could offer competitive advantages for terrestrial service providers who chose to offer it to their subscribers. Also, D2D's emergency messaging offers enormous safety-of-life value. And as noted earlier, D2D can provide enterprise synergies in areas where there is market convergence and cost savings. The market is still nascent with only two companies that have rolled out D2D services with established pricing plans:

- Apple's emergency SOS service is free for two years after the activation of iPhone 14 or iPhone 14 Pro. There is currently no indication regarding what these services will cost after the first two years.
- Bullitt will charge $4.99 per month for customers to connect their satellite-enabled Android smartphones to a GEO satellite, when out of range of Wi-Fi or cellular coverage.

How much are wireless subscribers willing to pay for D2D services? In some regions and countries, public agencies might subsidize emergency messaging and text services, particularly if they offer societal value such as emergency messaging, similar to the FCC's 911 service and other public alert requirements. Revenue forecasts will begin to gain clarity as more D2D services roll out with pricing plans, and consumers and regulators respond. However, the benefits of D2D services extends far beyond the revenue generation potential and a balanced assessment will require both increased market maturity and transparency.

Unpredictable International Markets. The addressable international market for D2D mobile data is also unpredictable. For instance, price elasticity varies significantly for various countries.[‡‡‡‡] In some countries, such as India, mobile data has a very high demand elasticity. For instance, 1 GB of mobile data in India costs approximately $ 0.26. By comparison, the $8.53 for 1 GB of mobile data is the global average.[63]

Geographically Independent Areas. In the SCS NPRM, the FCC proposed to "minimize the possibility for interference between geographically adjacent markets" as an initial step to "limit the provision of supplemental coverage from space to instances where a single terrestrial licensee holds all co-channel licenses in the relevant band throughout one of six Geographically Independent Areas (GIA), including (1) the contiguous United States (CONUS); (2) Alaska; (3) Hawaii; (4) American Samoa; (5) Puerto Rico/U.S. Virgin Islands (USVI); and (6) Guam/Northern Mariana Islands."[64] How will this GIA restriction play out when some providers, such as T-Mobile, enjoy contiguous nationwide coverage, holding all co-channel licenses in the PCS G-Block,[§§§§] while other providers have a noncontiguous patchwork of different frequencies?

Conclusion

Billions of smartphone users across the planet are fueling the "connectivity anywhere" zeitgeist. D2D services are well positioned to ride this wave—allowing consumer grade cell phones to connect to satellites, which will significantly expand the overall satcom market size. D2D connectivity is still in an early market phase and influenced heavily by partnerships designed to combine the strengths of satellite operator coverage with the large subscriber base of mobile network operators. We can expect to see more D2D service announcements over the next few years as the technology matures and as D2D innovators establish mutually beneficial partnerships with existing MNOs, cell phone manufacturers, and IoT vertical markets.

[‡‡‡‡]Price elasticity is the degree to which individuals, consumers, or producers change demand or the amount supplied in response to price changes.
[§§§§]The T-Mobile-Sprint merger allowed T-Mobile access to Sprint's nationwide PCS G Block spectrum 1910-1915 MHz and 1990-1995 MHz. Combined spectrum synergies between T-Mobile and Sprint are significant.

Investors and other stakeholders should be cautious as D2D providers attempt to expand capabilities from lower throughput messaging and texts to more demanding applications, such as voice, video streaming, and other broadband applications that require continuous connectivity at higher bandwidths and often low latencies. In the meantime, Apple's emergency SOS service has already saved lives. Indeed, nationwide coverage for simple two-way text messaging serves the public interest by promising critically needed connectivity for unserved areas. Nascent D2D services are based upon two different spectrum methods or strategies, each offering distinct strengths and weaknesses.

- *D2D satellite spectrum approach.* This model provides satellite-enabled D2D service using spectrum already **allocated for satellite services**. The ability to operate is not dependent upon future FCC waivers and ITU decisions. However, this service depends upon the market readiness of **modified** smartphones with embedded chipsets to enable operations with satellite spectrum.

- *D2D terrestrial spectrum approach.* This model provides satellite-enabled D2D service using spectrum **allocated for terrestrial mobile services** and licensed to partner MNOs. This model depends upon FCC waivers, and ultimately ITU support to gain global market traction and regulatory certainty. This service works with **unmodified or** "off-the-shelf" smartphones offering "first to market" advantage.

Future spectrum regulatory decisions by the FCC in the United States and domestic regulators of other countries combined with the result of ITU'S 2023 World Radio Conference and beyond will shape the future of D2D. How these decisions play out could limit the spectrum and coverage areas available for some forms of D2D services and/or could provide needed regulatory certainty to unlock the potential and facilitate investment in this promising new service.

Currently, the D2D market is still forming and exhibits the following characteristics:

- **Competitive.** MNOs will compete based upon cost, coverage, and quality of service. The ability to address dead zones using satellites for emergency or text messaging will become a capability discriminator to reduce subscriber churn and to attract new customers.

- **Cooperative.** Strategic partnerships are emerging which will be key to supporting both satellite communication providers and MNOs. As the $28 billion per year satcom market joins the $1 trillion per year MNO market, the synergy could create a rising tide for all stakeholders. We expect that some D2D capabilities can coexist for the same customer base. For instance, an Apple iPhone 14 handset offers "built in" emergency SOS services via Globalstar commercial LEO constellation. The iPhone 14 user could also use this same device to access text messaging services enabled by Lynk Global or AST SpaceMobile.

- **Disruptive.** The following areas could face some disruptive forces:

  - *IoT.* New D2D capabilities could displace existing IoT providers and other connectivity providers whose service offerings are not built into widely distributed consumer grade handsets or terminals.

  - *Traditional MSS.* New D2D services could pose a market threat to both traditional satellite phone service providers and manufacturers of satellite terminals. Future satellite service customers may wonder—why purchase and pay for both a cell phone and a satellite phone when one device can connect to both space and terrestrial networks?

Another wildcard hanging over D2D services is the size of the addressable market, and the degree to which competition, co-opetition, and disruption will shape the D2D landscape. Regardless of the market maturation path, D2D technology is a game changer that could fundamentally change the satcom market by expanding connectivity options for customers while bringing significant value to communication providers in terms of efficiencies and cost savings as well as new revenue potential. This service maturation will be part of the larger transformative evolution taking place within the telecom sector to meet the planet's growing need for increased mobile connectivity. This new global wireless infrastructure market will involve a great convergence of satellite, terrestrial, and IoT networks, along with a range of evolving devices, consumer and business applications.

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