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Telecom & Digital Infrastructure Technology and Investment Trends

A look ahead into 2025

December 10, 2024

Preface

In 2024, the digital infrastructure market displayed a "K"-shaped divergence in performance. Some sectors saw strong investment interest while others witnessed significant challenges. Interest in data centers remained strong, driven primarily by demand for AI infrastructure and cloud services. Other sectors including Low Earth Orbit (LEO) satellite constellations and submarine fiber deployments saw positive dynamics. In contrast, many telecom assets struggled, reflecting challenges such as slower ROI in 5G deployments and regulatory pressures. As a result, while data centers focused on aggressive expansion, the telecom sector pivoted toward consolidation.

As we enter 2025, uncertainty looms over various sectors in the digital infrastructure space. Several factors will influence its evolution, including a new U.S. administration with a different stance on telecom, AI, and blockchain regulation; rising geopolitical tensions affecting supply chains and sovereign digital infrastructure dynamics; increased competition in the AI space, which directly impacts demand for digital infrastructure; and the growing threat of major cybersecurity risks at the national level, as demonstrated by the recent “Salt Typhoon” cybersecurity incident.

In the data center space, the pace of investments is likely to continue, with data centers of 1 GW and larger being planned in the U.S., a move toward nuclear energy to power them, and a rapid expansion into global markets to support distributed AI infrastructure for training and inference workloads. However, the investment risk is also rising, given the speculative nature of a significant number of data center infrastructure investments worldwide, many of which cater to a small number of hyperscale customers.

Unlike the vibrant data center sector, the downturn in telecom capital expenditure (capex) that began in mid-2023 persisted through 2024. Telecom service providers continued to grapple with heavy debt loads and stagnant revenue streams, as 5G failed to deliver the anticipated growth boost. Meanwhile, investments in fiber networks under the BEAD initiative have yet to make a significant market impact. This backdrop set the stage for notable acquisitions and divestments, including T-Mobile's acquisition of US Cellular and Vodafone's sale of tower assets.

In the satellite industry, the gap between SpaceX’s Starlink, which has over 6,500 satellites in orbit, and its competitors continues to widen. Starlink is diversifying its service offerings, with its direct-to-cell service in partnership with T-Mobile nearing commercial launch. Additionally, Starlink’s fixed wireless access services are becoming a viable alternative for rural users who currently depend on wireless ISPs.

Last but not least, the subsea cable market remains a bright spot, driven by sustained growth fueled by hyperscalers, who are now the central players in this geopolitically sensitive segment.

In 2024, our team had the privilege of contributing to several cutting-edge projects in data center, Artificial Intelligence compute infrastructure and telecom network infrastructure. Highlights include:

- Led various strategy workshops to assess the geopolitical impacts on the digital infrastructure value chain, including

compute and storage chipsets, networking, data and cybersecurity solutions, as well as mobile, satellite, and submarine networks.
- Collaborated with stakeholders to evaluate the impact of AI developments on data centers, cloud infrastructure, connectivity, and cybersecurity strategies.
- Conducting an assessment for the Canadian telecom regulator on the July 2022 Rogers network outage, which impacted over 12 million subscribers.
- Providing advisory services for the deployment of 5G private wireless networks across various geographies and sectors, including utilities and manufacturing.
- Advising on multiple investments in subsea cable projects, including a significant trans-oceanic initiative.
- Offering guidance on the planning and assessment of LEO satellite constellations, covering broadband and direct-to-device services.

During 2024 we published a selection of Insight Notes on some of the prominent topics where our team participated in servicing clients, of which we note:

Reassessing mmWave Spectrum Valuations. In a discreet decision, T-Mobile recently returned authorizations for 520 licenses in the 28 GHz band to the FCC. Similarly, US Cellular marked down its millimeter wave (mmWave) spectrum value by 46%, incurring a $131 million impairment charge. These actions stand in stark contrast to the billions spent in past FCC auctions to acquire mmWave spectrum, alongside acquisitions by major MNOs. The disparity in mmWave spectrum valuations now compared to just a few years ago is striking. This Insight Note will trace the trajectory of mmWaves' perceived value over recent years, analyzing what may have driven these high valuations and the implications for mmWaves and the broader telecom industry.

Risks in Direct to Device Satellite Communications. Direct-to-device (D2D) satellite communications present significant challenges, both financial and technological, that are closely interconnected. Addressing one set of challenges often increases the risk in the other. Different D2D constellations have adopted various strategies to balance commercial and technological risks. In this Insight Note, we highlight some of the key technological risks and examine how two leading satellite constellations are currently working to mitigate them.

Telecom Network Resiliency - Strategies and Lessons from Major Outages. During a period of two years, three catastrophic telecommunications network outages drew the ire of customers and regulators who initiated probes to understand the incidents and prevent future occurrences. The outages at Rogers (Canada), Optus (Australia), and AT&T (US) underscored the critical dependency of modern economies on telecommunications networks. Network outages impact more than just calling, texting, or browsing; they disrupt life-saving emergency services, financial transactions, and connected devices in various sectors. This Insight Note outlines regulatory recommendations and emphasizes the importance of auditing internal processes and conducting thorough pre-investment technical due diligence for telecom investments.

Mobile Infrastructure Capex: Permanent Weakening or Short-Term Decline. Mobile infrastructure capital expenditures has declined significantly since the second quarter of 2023, following a wave of spending on 5G, and no recovery is yet in sight. While the mobile industry has faced such declines in the past, signs suggest that the current weakness could be longer and deeper than previous downturns. In this insight note, we explore the top five threats that could turn the current spending cycle into a long-term bear market for mobile infrastructure.

Evolving Trends in Positioning, Location and Timing Technologies. Several companies provide location and positioning services using a variety of technologies, including mobile network operators, satellite operators, and specialized location service providers. This Insight Note examines potential developments in this market segment in light of recent investments and technological advancements. It focuses on emerging use cases and potential requirements for location and positioning services to provide context for the future operating environment for both current service providers and new entrants.

Exploring New Opportunities in Active Mobile Infrastructure Sharing. The evolving landscape of the mobile industry is prompting various stakeholders to explore active mobile infrastructure sharing initiatives. Technological advancements, notably in Open RAN and network slicing, are driving this recent surge of interest in active infrastructure sharing. In this Insight Note, we outline several critical factors essential for evaluating and implementing such sharing models effectively.

Mapping the Road Towards 6G. Recent announcements from both the ITU-R and 3GPP provide valuable insights into the roadmap for the emergence of 6G technology. Based on historical norms, we anticipate meaningful commercial 6G deployments to commence around 2031. While the requirements and specifications for 6G are yet to be defined, this Insight Note delves into the pivotal factors shaping the definition of 6G.

Looking ahead to 2025, it is challenging to generalize trends across the diverse segments of the digital infrastructure space, especially against the backdrop of slowing major economies. Each segment must be evaluated independently, considering the economic environment and key influencing factors, including the growing role of geopolitical tensions. Some themes to watch include:

- **AI platforms**: The entire value chain, from semiconductors to edge cloud infrastructure and Large Language Model platforms.
- **Direct-to-device satellite services**: The anticipated launch of the first service using the same spectrum as terrestrial mobile networks and its potential impact on the competitive landscape.
- **Quantum technology**: Applications in both computing and cybersecurity.
- **Government policies and subsidies**: Effects of recent elections and policy shifts on funding for telecom projects, such as the BEAD initiative in the U.S. and similar programs globally.
- **Infrastructure resiliency**: The growing strategic importance of wireline, wireless, and cloud infrastructures for national sovereignty and economic development.
- **Sustainability**: Challenges facing cloud and telecom infrastructures, particularly with the demands of AI and 5G.

In conclusion, we expect economic conditions and geopolitical tensions to be pivotal factors shaping investments in telecom, cloud, and digital infrastructure assets in 2025. A potential disinflation in asset valuations may remind investors of the critical importance of thorough technical and commercial due diligence to mitigate losses from hype-driven bubbles.

In This Edition

Insight Note

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Unfulfilled Promise: Reassessing mmWave Spectrum Valuations and Shifting Use Cases

Overview. In a discreet decision, T-Mobile recently returned authorizations for 520 licenses in the 28 GHz band to the FCC. Similarly, US Cellular marked down its millimeter wave (mmWave) spectrum value by 46%, incurring a $131 million impairment charge. These actions stand in stark contrast to the billions spent in past FCC auctions to acquire mmWave spectrum, alongside acquisitions by major MNOs. The disparity in mmWave spectrum valuations now compared to just a few years ago is striking. This Insight Note will trace the trajectory of mmWaves' perceived value over recent years, analyzing what may have driven these high valuations and the implications for mmWaves and the broader telecom industry.

Challenging Business Case. The case of T-Mobile and its experience with mmWave warrants closer examination. Originally, T-Mobile held 550 licenses under the Upper Microwave Flexible Use Service (UMFUS) with buildout deadlines set for June 1, 2024. By early 2024, T-Mobile had managed to meet deployment requirements for just 12 licenses. Additionally, the company requested that the FCC allow it to retain a limited number of Census Tracts for 18 licenses while relinquishing the remainder of each license's service area. Notably, T-Mobile also surrendered all rights to 520 remaining licenses, acknowledging it could not meet the required deployment thresholds for those licenses.

In its waiver request, T-Mobile explained that mmWave technology had fallen short of performance expectations set during the FCC's Spectrum Frontiers initiative. It implied that the technology's current capabilities did not justify a positive return on investment, especially for use cases such as mobile and fixed wireless access (FWA). One clear exception is in highly dense environments, like stadiums and arenas, which are covered by the retained 18 partial licenses. The main limitations identified include mmWaves' limited range and the need for line-of-sight conditions, impacting performance stability.

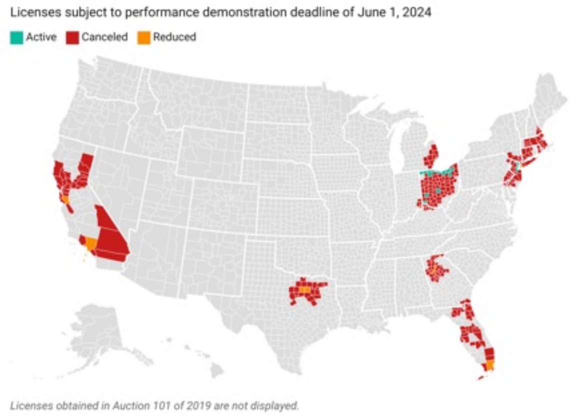


Figure 1 T-Mobile's UMFUS/28 GHz license status.

The Genesis of Inflated Expectations. The wave of interest in mmWave spectrum can be traced back to Verizon's early initiatives to provide FWA services. In 2015, Verizon formed the 5G Technical Forum (5G TF) to expedite 5G deployment, using proprietary specifications focused on mmWave spectrum for fixed 5G services. This initiative set the stage for Verizon's mmWave spectrum accumulation.

In 2017, Verizon initiated a strategic push to acquire mmWave spectrum, beginning with its $1.8 billion acquisition of XO Communications, which held long-term leases for 28 GHz and 31 GHz LMDS licenses. This was followed in 2018 by Verizon's purchase of these licenses directly from

Nextlink for a reported $500 million. That same year, Verizon won a high-profile bidding war against AT&T to acquire Straight Path Communications, which held a substantial portfolio of nationwide 39 GHz licenses and 28 GHz licenses across major markets, for $3.1 billion. Although Straight Path was a small company with only nine employees and annual revenue of approximately $2.1 million (with $461,000 generated from spectrum leasing), its licenses represented significant strategic value for mmWave holdings, influencing mmWave valuations in both auctions and secondary markets.

Building on these acquisitions, Verizon continued its mmWave expansion by participating in FCC Auction 101 in 2019, spending approximately $500 million to acquire additional 28 GHz licenses. These moves underscored Verizon's commitment to mmWave spectrum as a foundational asset for its 5G network strategy, while also setting a high valuation benchmark for future mmWave transactions and auctions.

Verizon’s strategic approach shifted dramatically following T-Mobile's 2018 announcement of its plan to acquire Sprint. This acquisition provided T-Mobile with an average of 140 MHz of valuable 2.5 GHz mid-band spectrum, positioning it to rapidly deploy mobile 5G services and establishing a strong competitive edge. In contrast, Verizon, lacking significant mid-band spectrum holdings, pivoted toward mmWave spectrum as a temporary solution to support mobile 5G deployment. Around this time, Verizon discontinued its 5G TF initiative and aligned its deployments with 3GPP’s 5G NR standards, which were by then finalized.

Verizon maintained a public commitment to mmWave technology until 2022, by which time it had acquired an average of 160 MHz in the 3.8 GHz C-Band spectrum for a significant $52 billion during the 2021 auction—double the $26 billion all-stock price T-Mobile paid for Sprint. With this new mid-band spectrum, Verizon’s focus shifted heavily toward C-Band deployment, and the interest in mmWaves gradually faded. In fact, Verizon subsequently sold 208 licenses in the 28 GHz band, including some covering major metropolitan areas, to GeoLinks, citing lack of compatibility with its mobile strategy.

The Path Forward. To understand the utility and value of mmWave spectrum, it’s important to consider its various applications. These can be categorized into four main areas: mobile, Fixed Wireless Access (FWA), capacity hotspots, and private wireless networks.

Mobile service. Verizon is the only major MNO that has committed to mobile mmWave (5G Ultra Wideband). However, its deployment has stalled, with around 35,000 base stations reported in March 2022. This number covers a small fraction of Verizon’s total footprint (for contrast, Verizon provides national footprint with around 64,000 base stations). Despite initial promises, mmWave mobile deployments have fizzled out. Given that mobile applications have high $/bps value, mmWave cannot maintain its previous valuations unless its utility is demonstrated, which remains unproven today.

Fixed wireless access. Although mobile mmWave has not succeeded as expected, its use in Fixed Wireless Access (FWA), particularly for enterprise data backhaul and multi-dwelling units (MDUs), remains viable. This approach to mmWave deployment harks back to its traditional use in the 1990s. Verizon, for example, has expressed its intention to serve MDUs with mmWave technology. Starry, another company focused on this market segment, encountered significant financial challenges and filed for Chapter 11 bankruptcy in early 2023, later restructuring as a private company.

In addition to the MDU market, mmWave is also being explored in other residential fixed access services. From our experience, however, we observe a variety of performance challenges in these deployments. Consequently, FWA alone cannot justify the high valuations that mmWaves once commanded, based primarily on its potential for mobile services.

Capacity hotspots. The high density and open space of stadiums and arenas align well with mmWaves' line-of-sight and high-throughput capabilities. However, the service area, as defined by regulators, may not always be suitable for this application. For instance, while the 28 GHz spectrum is licensed over counties, other bands like 24 GHz and 37/39/47 GHz cover larger Partial Economic Areas. T-Mobile has demonstrated that smaller Census Tracts can work for this application, suggesting that regulatory definitions may not be flexible enough to accommodate capacity hotspots.

Private wireless networks. Many regulators, including those in Canada, China, France, Germany, Hong Kong, Japan, and the UK, have allocated mmWave spectrum for private wireless networks. These networks are particularly useful for enterprises requiring automation or high-bandwidth applications like video streaming. However, the high cost of mmWave equipment, especially in the absence of mobile use cases, could pose a challenge to widespread adoption. That said, there will be industries where mmWave is essential for meeting their specific needs, justifying the high costs.

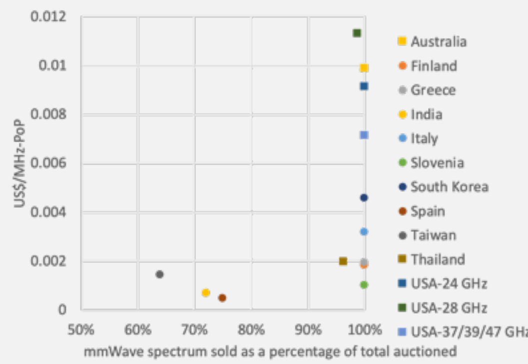
In summary, while mmWave spectrum has clear applications in certain sectors, its overall value may not live up to previous expectations, particularly in mobile services. However, its utility in FWA, capacity hotspots, and private wireless networks remains important, albeit at a smaller scale than initially anticipated.

Key Lesson. The recent high valuations of mmWave spectrum make sense primarily in the context of competition among major MNOs. Verizon, aiming to appear credible to financial analysts and market observers, invested heavily in mmWave—spending over $4 billion on spectrum acquisition and deploying around 35,000 cells along with the associated capex and opex to support this network. Through its 5G Ultra Wideband service, Verizon likely gained some benefits and, perhaps more crucially, reduced potential customer churn under competitive pressure from T-Mobile. For a large MNO, this level of expenditure may be justified as part of a broader competitive strategy.

However, smaller players should approach mmWave with caution, understanding the unique dynamics of this competitive "game" to avoid becoming burdened with overvalued assets that might not yield equivalent returns.

A Global Perspective on mmWaves

Outside of the United States and Australia, demand for mmWave licenses in spectrum auctions was relatively low. In many markets, mobile network operators, the primary bidders, were unwilling to pay much beyond the reserve price. For example, in Hong Kong, a free mmWave license was even declined. In South Korea, which was the first country to auction mmWave for 5G mobile services, the regulator had to revoke licenses from mobile operators for failing to meet deployment deadlines. Other regulators, such as those in Canada, have delayed auctions or completely scrapped plans for mmWave auctions.



mmWave pricing and demand at recent auctions. Circle: final price at reserve price; Square: final price at premium over reserve price.

Key Takeaways

- **Unmet Expectations:** mmWave spectrum has largely failed to meet the high expectations set by the FCC's 2016 Spectrum Frontiers initiative, which anticipated widespread use for mobile and FWA applications.
- **Inflated Valuations by Select MNOs:** mmWave spectrum valuations between 2018 and 2020 were driven by large MNOs, particularly Verizon, which lacked mid-band spectrum and sought to use mmWaves as a temporary solution for 5G services.
- **Shifting Focus of mmWave Use Cases:** Verizon initially pursued mmWaves for FWA applications but shifted to mobile services after T-Mobile announced its Sprint acquisition, which strengthened T-Mobile's 5G capabilities through its mid-band holdings.
- **Diminished Interest in Mobile Applications:** Verizon dropped its mobility service plan in mmWave spectrum following its $52 billion C-Band acquisition in 2021. T-Mobile surrendered 520 of its mmWave licenses, citing poor performance, and US Cellular recorded a $131 million impairment, reducing its mmWave spectrum value by 46%.
- **Limited Use Cases Beyond Mobile:** With mobile applications no longer driving mmWave deployments, it is unlikely that FWA, capacity hotspots, or private wireless network applications alone can sustain the high valuations initially set for mmWaves based on mobile use cases.
- **Caution for Smaller Players:** Investors and smaller telecom players should approach telecom asset valuations cautiously. In the case of mmWave spectrum, high expenditures—over $6 billion in Verizon's case—were driven by competitive pressures between major MNOs. What may have been viable for large MNOs like Verizon does not necessarily translate to sound investments for smaller entities.

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Understanding the Risks in Direct-to-Device Satellite Communications: Insights from SpaceX and Globalstar

Overview. Direct-to-device (D2D) satellite communications present significant challenges, both financial and technological, that are closely interconnected. Addressing one set of challenges often increases the risk in the other. Different D2D constellations have adopted various strategies to balance commercial and technological risks. In this Insight Note, we highlight some of the key technological risks and examine how two leading satellite constellations are currently working to mitigate them.

Approaches to the D2D Market. Different types of companies are gearing up to offer mobile users seamless satellite connectivity. These include space and startup companies (e.g., SpaceX, AST SpaceMobile, Lynk Global), established mobile satellite service (MSS) providers (e.g., Globalstar, Iridium), and traditional satellite operators (e.g., Viasat, Intelsat, Eutelsat).

These companies employ varied approaches to delivering D2D services, often shaped by their spectrum strategies, which are influenced by their core competencies and legacies. For example, space and startup companies are forming partnerships with mobile network operators to utilize mobile spectrum for satellite services under new regulatory frameworks like the Supplementary Coverage from Space (SCS) in the U.S. MSS companies, on the other hand, leverage their existing MSS spectrum, while traditional satellite operators pursue technological and regulatory adjustments to enable D2D services using their current spectrum assets, as seen in their involvement with 5G standard-setting bodies.

Frequency Bands for Satellite 5G Services

To achieve economic viability, D2D services must operate in frequency bands already supported by user devices. The adoption of satellite bands in 3GPP specifications is therefore a crucial milestone, facilitating system testing and ensuring interoperability. Additionally, it signals potential future strategies, as constellation operators lay the groundwork for expanding their services.

The 3GPP has categorized frequency bands for Non-Terrestrial Networks (NTN) into two main classes. The first class includes 5G bands, primarily driven by personal connectivity use cases. The second class consists of LTE bands, which are mainly geared toward IoT connectivity. The table below highlights the frequency bands identified for 5G NTN use cases. The S and L bands are designed for handheld devices, while the Ka band is intended for high-gain, small aperture antennas, such as those used in fixed wireless access and on vehicles. However, Ka band owners have expressed interest in serving mobile handsets, adding complexity to the market's competitive landscape. It's important to note that today's D2D constellations offering LTE services are not formally aligned with 3GPP specifications.

Table 1 3GPP frequency bands for 5G NTN.

Rel.	Band	Uplink	Downlink
Rel-17	n256	1980 - 2010 MHz	2170 - 2200 MHz
Rel-17	n255	1626.5 - 1660.5 MHz	1525 - 1559 MHz
Rel-18	n254	1610 - 1626.5 MHz	2483.5 - 2500 MHz
Rel-18	n512 n511 n510	27.5 - 30.0 GHz 28.35 - 30.0 GHz 27.5 - 28.35 GHz	17.3 - 20.2 GHz 17.3 - 20.2 GHz 17.3 - 20.2 GHz
Rel-19	TBD	*12.75-13.25 GHz and 13.75-14.5 GHz* *12.70-13.25 GHz and 13.75-14.5 GHz*	*10.70 - 12.75 GHz* *10.70 - 12.70 GHz*

To illustrate the risks associated with these different strategies, we compare the approaches of two leading constellations: SpaceX, which is enhancing its Starlink constellation to offer D2D services starting in the fall of 2024, and Globalstar, which currently provides D2D services through its partnership with Apple.

SpaceX Approach. SpaceX's foray into the D2D market (which it calls direct-to-cell) was cemented with the partnership with T-Mobile to operate D2D in T-Mobile's PCS G band under the SCS framework, which the FCC adopted in March of 2024. SpaceX plans to launch test services in the fall of 2024, followed by voice and IoT services in 2025. Since it announced its partnership with T-Mobile, SpaceX announced similar tie-ups with Rogers in Canada, Optus in Australia, One New Zealand, KDDI in Japan, Salt in Switzerland, and Entel in Chile & Peru.

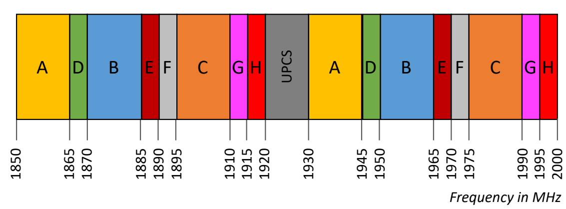

Figure 1 PCS band plan. SpaceX will operate in T-Mobile G block in the US.

For this service, SpaceX is launching Starlink Gen 2 satellites with a D2D payload into an orbit between 340 -360 km. There are at he time of writing this Note over 130 D2D satellites launched to date. The D2D satellites will interconnect over optical intersatellite links with other Starlink satellites at their typical altitude of 580 km (check). The benefits of operating at low altitude is reducing the time it takes for signals to travel between the earth and a satellite, as well as reducing the path loss which leads to higher throughput and capacity.

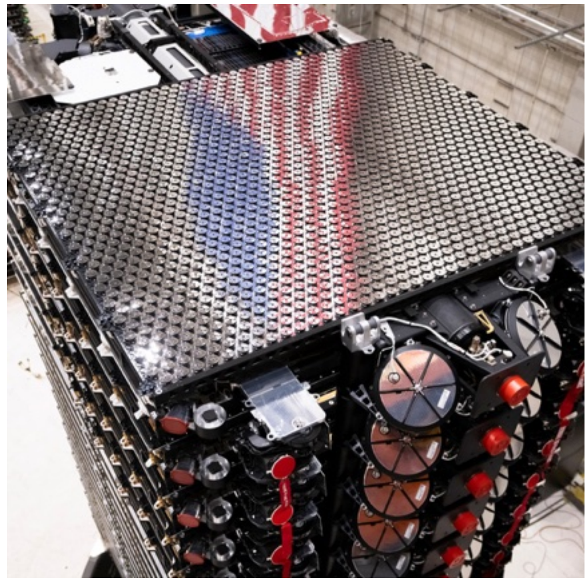

Figure 2 6 DTC satellites stacked for launch. SpaceX Gen 2 satellite will be launched using Falcon 9 rocket. [Source: SpaceX]

The communications payload is an entire LTE base station (eNB). 5G services are a roadmap item. SpaceX will host a core on the ground which will connect to a T-Mobile, or another carrier mobile core in typical roaming arrangement.

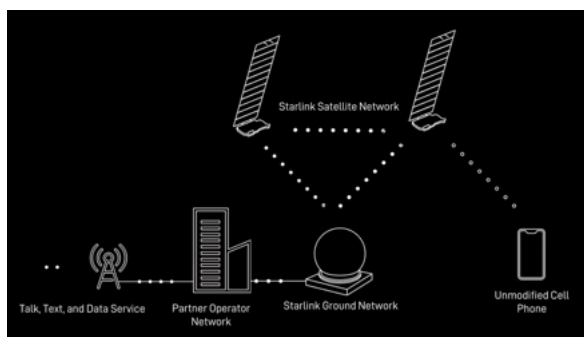

Figure 3 SpaceX network architecture. [Source: SpaceX]

Globalstar's Approach. Unlike SpaceX, Globalstar leverages its MSS spectrum and existing satellite constellation to offer D2D services. A key element of this strategy is its partnership with Apple, which began with the launch of the iPhone 14 in 2022. Globalstar's service currently supports emergency texting, branded by Apple as "Emergency SOS via satellite." Voice services are planned for future releases, pending upgrades to the

Table 2 Overview of SpaceX and Globalstar's approach to direct-to-device communications.

Aspect	SpaceX	Globalstar
Altitude and Coverage	Operates at 340 km for reduced latency and better signal strength.	Operates at 1,414 km, offering wider coverage but higher latency and propagation losses.
Spectrum Utilization	Uses terrestrial mobile spectrum under frameworks like SCS; requires partnership with mobile network operators.	Leverages existing MSS spectrum; operates independently of mobile network operators.
Interference Challenges	Faces strict regulatory limits on out-of-band emissions, with a focus on minimizing interference with terrestrial networks.	Encounters no interference issues with terrestrial networks due to MSS spectrum.
Service Evolution	Plans to start with text services and expand to voice and internet data.	Currently provides emergency text services; plans to introduce voice services in a future constellation.
Technology Trade-offs	Lower altitude necessitates more satellites, increasing cost but improving performance (e.g. capacity).	Higher orbit requires more powerful satellites and antenna systems.
Partnerships	Collaborates with mobile operators to integrate satellite services.	Partners with Apple, embedding emergency services into iPhones.

Globalstar constellation, currently being developed by MDA.

The service operates over 24 Globalstar Gen-2 satellites, which orbit at an altitude of 1,414 km, with a signal travel time of approximately 9.4 milliseconds to reach Earth. These satellites are set to be replaced in the coming years by more advanced models designed to better address the D2D market, which are also under development by MDA.

Globalstar's user downlink operates in the S-band (2483.5 - 2495 MHz), with an upper limit extending to 2500 MHz for international markets. The user uplink is in the L-band (1610 - 1618.725 MHz), while Globalstar ground stations utilize the C-band. Globalstar satellites use a bent-pipe, or transparent architecture (as defined by 3GPP), relaying terrestrial traffic. The ground stations host the baseband units and communicate with the satellites using C-band spectrum.

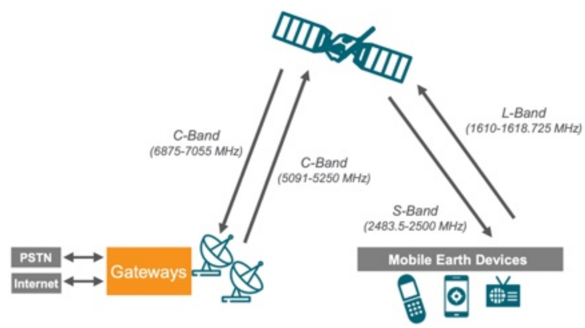

Figure 4 Gobalstar network architecture. [Source: Globalstar]

While Globalstar's service is constrained by its existing constellation and network architecture, it benefits from widespread availability due to its MSS licensing across the globe. This licensing frees Globalstar from the regulatory frameworks similar to the FCC's SCS, and more importantly, it does not require spectrum coordination with local mobile network operators, unlike SpaceX.

The Range Challenge. D2D communications operate over long distances—340 km for SpaceX and 1,414 km for Globalstar. These communications are directed to user devices, which imposes constraints related to the device's power and antenna capabilities. One of the significant challenges is 'closing the link budget,' which involves ensuring communication at a sufficient data rate that meets the service requirements while also supporting enough network load to achieve profitability. As a result, D2D services typically begin with text messaging, which requires low throughput, followed by voice and data services at a later stage (note that AST SpaceMobile is targeting data services to start).

Long range creates other challenges aside from the high propagation losses that adversely impact the received signal power. However, we stress range here because of its impact on a number of dependencies, such as satellite antenna design and power capabilities, which affect performance and the economic viability of the constellation. It is notable for instance that SpaceX has lowered the altitude of its D2D satellites from the typical 550 km used in Starlink satellites for fixed wireless access to 340 km to optimize these factors.

The Interference Challenge. The interference challenge is particularly significant for D2D constellations utilizing terrestrial mobile spectrum. Regulators have begun addressing this issue through frameworks like SCS, as mentioned above, where satellite communications are treated as secondary to mobile services in specific terrestrial spectrum bands licensed to mobile operators over defined geographic areas. For instance, the FCC has established a geographically independent area (GIA) that covers the entire continental United States. This means that operators aiming to provide D2D services must hold a license for all 48 contiguous states to minimize co-channel interference with neighboring regions. Additionally, the FCC has imposed a stringent limit on the aggregate out-of-band emission power flux density (PFD) of -120 $dBW/m^2/MHz$ across all frequency bands to protect against adjacent channel interference.

Recently, SpaceX argued that this limit is overly restrictive and petitioned the FCC for a band-specific limit that aligns with the ITU-defined threshold, where satellite interference power is 6 dB below the noise level (I/N = -6 dB). Mobile network operators like AT&T, Verizon, and Dish Networks opposed this petition, claiming it would negatively impact their networks. AT&T, in particular, expressed concern, noting that SpaceX's proposal could cause an 18% average reduction in downlink throughput in their PCS C block markets.

While mitigating adjacent channel interference is possible through measures such as antenna design and power output adjustments, these solutions can impact the cost and performance of satellites, thereby affecting the business case. This underscores the importance of design choices and engineering trade-offs, which directly influence the financial viability of D2D services.

Key Takeaways

- Addressing the range and interference challenges requires engineering trade-offs the significantly impact performance and profitability.
- Direct-to-device (D2D) communications face several challenges, with range (distance between the satellite and mobile device) and interference management being critical.
- The two leading D2D constellations today are SpaceX, set to begin offering services in fall 2024, and Globalstar, which already provides D2D services through a partnership with Apple.
- SpaceX and Globalstar differ in their business models and technology strategies, influenced by spectrum regulations and legacy licenses, which significantly impact performance and profitability.
- Globalstar operates at an altitude of 1,414 km, much higher than SpaceX's 340 km, leading to greater propagation losses that require higher system gain to overcome for the same grade of service.
- SpaceX uses terrestrial mobile spectrum under new regulatory frameworks like SCS, necessitating licenses across large areas (the entire continental U.S. in SCS) to avoid co-channel interference. In contrast, Globalstar leverages its existing MSS spectrum, already licensed globally, enabling operation independent of new frameworks like SCS.
- Frameworks like SCS impose additional requirements on D2D satellite constellations to minimize interference with terrestrial mobile networks. These requirements include out-of-band emission limits and geographic licensing coverage.
- Addressing the range and interference challenges requires engineering trade-offs that have significant impacts on both performance and profitability of the D2D satellite constellation.

Telecom Network Resiliency: Strategies and Lessons from Major Outages

Overview. During a period of two years, three catastrophic telecommunications network outages drew the ire of customers and regulators who initiated probes to understand the incidents and prevent future occurrences. The outages at Rogers (Canada), Optus (Australia), and AT&T (US) underscored the critical dependency of modern economies on telecommunications networks. Network outages impact more than just calling, texting, or browsing; they disrupt life-saving emergency services, financial transactions, and connected devices in various sectors. This Insight Note outlines regulatory recommendations and emphasizes the importance of auditing internal processes and conducting thorough pre-investment technical due diligence for telecom investments.

Robustness of Telecommunication Networks. There is a perception that network failures and service outages are occurring with higher frequency than in the past. While there is no specific statistic to confirm this, the increasing dependency on connectivity heightens our sensitivity to these outages. Modern telecom networks are complex, combining various generations of technology, and are more distributed and disaggregated, raising the number of nodes and interfaces. This creates a challenging environment for software and hardware management, including testing. The three outages reviewed here, and many others, are the result of human errors, highlighting the complexity of current telecom networks.

The AT&T Network Outage. The AT&T mobile network outage began on the morning of February 22, 2024, and lasted at least 12 hours. During this time, all voice and 5G data services were unavailable for over 125 million devices, including those of FirstNet users. The outage blocked more than 92 million voice calls and prevented over 25,000

Network Resiliency and Reliability in Pre-Investment Due Diligence

Network failures are drawing increased scrutiny from regulators, raising the likelihood of financial penalties, as seen on several occasions. Outages negatively impact brand reputation and result in direct financial losses due to client compensation. This underscores the importance of auditing for network reliability and resiliency in pre-investment due diligence processes. Reliability and resiliency involve validating network architecture, reviewing configuration and incident management processes, testing software and hardware, and evaluating service level agreements with vendors.

Network performance is equally critical in due diligence as it relates to the service provider's competitiveness, including the ability to scale services, resource availability, cost, and the technology roadmap. Our extensive experience in technical and commercial due diligence in telecom assets has revealed significant shortcomings requiring substantial investment to rectify, such as improper equipment configurations. Addressing these issues through thorough due diligence enables investors to make informed decisions, ensuring their investments are robust and aligned with future growth and technological advancements.

Table 1 Overview of the AT&T, Optus and Rogers network failures.

	AT&T	Optus	Rogers
Date of outage	22-Feb-24	08-Nov-23	08-Jul-22
Time of failure	3:45 AM EST	4:05 AM AEDT	4:45 AM EST
Duration of outage	12 hrs	14 hrs	24 hrs
Outage footprint	Nationwide [all 50 states, Washington, DC, Puerto Rico, USVI]	Nationwide	Nationwide
Type of error	Misconfigured network element	Misconfigured network element that led to overload of IP routing information	Misconfigured network element that led to overload of IP routing information
Network element	Undisclosed	Core router	Core router
Impacted services	- Mobile Phone (3G, 4G, 5G) - Emergency services	- Mobile Phone (3G, 4G, 5G) - Internet services - Enterprise services - Emergency services - Financial services	- Mobile Phone (2/3G, 4G, 5G) - Internet services - Enterprise services - Emergency services - Financial services
Impacted customers	125 m devices	~10.2 million customers and 400,000 enterprises	> 11 million; all Rogers wireless, wireline and enterprise customers
Blocked emergency calls	> 25,000	Minimum 2,697 calls	911 calls were impacted
Customer refund	US$5	Additional 200 GB of data; volume and time validity depends on subscriber plan	C$5

emergency 911 calls. The FCC's report[1] concluded that an equipment configuration error caused the network to shut down as a protective measure. Neither AT&T nor the FCC specified the exact type of equipment involved in the failure.

The critical reasons for the AT&T outage are:

1. Configuration Error: A configuration error initiated the outage. The incorrect setup led to network instability and eventual failure.
2. Lack of Adherence to Procedures: Internal procedures were not followed rigorously, contributing to the propagation of the initial error.
3. Insufficient Peer Review: Changes made to the network were not adequately peer-reviewed before implementation.
4. Inadequate Testing: Both post-installation and laboratory testing were insufficient to catch and correct the configuration error.
5. Insufficient Safeguards and Controls: The network lacked adequate controls to prevent changes that could negatively impact core network functions.
6. Mitigation Failures: There were no effective controls to mitigate the effects of the outage once it began.

[1] Federal Communications Commission, "*February 22, 2024 AT&T Mobility Network Outage Report and Findings*," July 22, 2024. See: https://www.fcc.gov/document/fcc-issues-report-nationwide-att-mobility-outage

7. System Issues: A variety of system-level issues prolonged the outage even after the initial error was corrected.

The key recommendations to are:

1. Adherence to Best Practices: Emphasize the need for network operators to follow industry best practices and internal procedures when implementing network changes.
2. Mitigation Controls: Implement sufficient controls to prevent configuration errors from escalating and disrupting network operations.
3. Prompt Recovery Systems: Ensure systems and procedures have adequate capacity to facilitate prompt recovery from large-scale outages.
4. Industry Collaboration: Encourage collaboration among network operators to share best practices and improve overall network reliability and resilience.

The Optus Network Outage. The Optus network outage occurred on November 8, 2023, starting early in the morning and lasting approximately 14 hours. This outage affected a wide range of services, including mobile voice and data, SMS, and fixed-line internet. Over 10 million customers across Australia were unable to make phone calls, access the internet, or use emergency services. The outage prevented at least 2,697 emergency calls to 000 and caused significant disruptions to about 500,000 businesses and public services nationwide.

The outage was triggered when several Optus routers automatically self-isolated to protect themselves from an overload of IP routing information. This happened during a software upgrade, when the network received changes in routing information from an alternate Singtel peering router. These changes propagated through multiple layers of the IP Core network. When the pre-set safety limits on Optus network routers were exceeded, the routers self-isolated causing a loss of connectivity with the core network.

The report on the outage by the Department of Infrastructure, Transport, Regional Development, Communications and the Arts does not delve into the specific reasons for the outage[2]. The report is focused on providing recommendations, primarily on addressing emergency services. Of the list of 18 recommendations, some of the key ones include:

1. Network Redundancy: Ensure sufficient network redundancy and the ability to remotely access and activate network management tools.
2. End-to-End Testing: Carriers should conduct semi-annual end-to-end testing of the Triple Zero ecosystem to ensure network functionality and device interoperability during outages.
3. Temporary Roaming: Work on implementing temporary roaming during outages, learning from international practices.
4. Mutual Assistance: Establish mutual assistance arrangements between telecommunications providers to manage and resolve outages.
5. Central Coordination Point: Enhance the Protocol for Notification of Major Service Disruptions with detailed requirements for government communication and collaboration during outages.
6. Communication Standards: Develop standards requiring carriers to provide specific outage information to customers.

The Rogers Network Outage. The Rogers network outage began on July 8, 2022, and lasted for nearly 24 hours before all services were restored. This nationwide outage

[2] Department of Infrastructure, Transport, Regional Development, Communications and the Arts, "*Review into the Optus outage of 8 November 2023 – Final Report*", March 2024. See: https://www.infrastructure.gov.au/department/media/publications/review-optus-outage-8-november-2023-final-report

impacted approximately 10 million wireless customers and 2.25 million wireline subscribers across Canada, disrupting mobile voice and data services, internet access, and landline services. The outage severely affected critical services, including banking transactions, healthcare operations, and public safety communications.

The Rogers outage was caused by human error in configuring a router within the Rogers IP network. The configuration error resulted in a flood of IP routing information into the core network routers, triggering the outage.

In our publicly available report to the CRTC on the assessment of this outage[3], we listed several lessons learned, which include:

1. Implement router overload protection in the IP core and distribution networks.
2. Separate the network management layer physically and logically from the data network.
3. Provide the network operation centre and other critical remote sites with a secure backup connectivity from third-party telecom network operators.
4. Ensure that the audit process for network configuration changes is effective and involves different teams within the organization, such as engineering, operations, and project management. It is also advisable to involve equipment vendors where the configuration changes pertain to critical infrastructure, such as the IP core network.
5. Conduct lab tests of planned configuration changes and ensure that the lab equipment and test scenarios accurately reflect the production network.
6. Carefully manage the number of configuration changes completed in a single maintenance window and leverage tools and processes for automatic rollback of configuration parameters.

Anatomy of the Optus and Rogers Network Outages

The Rogers and Optus outages share similarities in their dynamics, involving similar network elements. In both instances, a Border Gateway Protocol (BGP) crash led to the network ceasing to advertise its presence to other networks, causing a near-complete traffic loss.

Restoration of networks from outages is often intermittent, gradual, and conducted in phases, prioritizing specific services and geographies. For example, AT&T prioritized restoring services to FirstNet users during their outage.

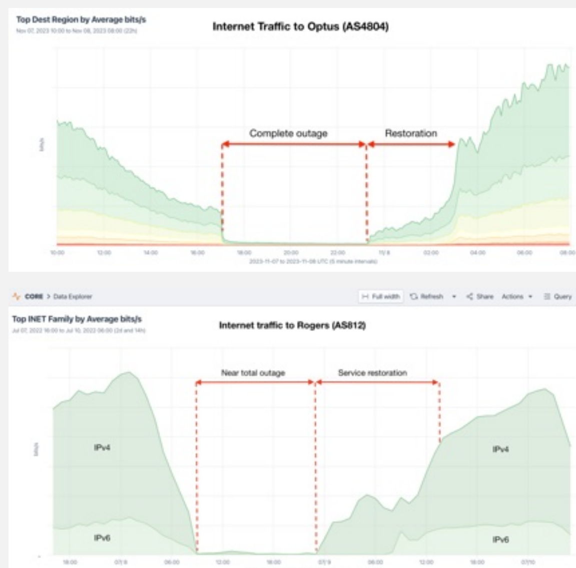

Figure 1 Traffic in Optus (top) and Rogers (bottom) outages. [Source: Kentik]

7. Implement an automated alarm prioritization solution to suppress unnecessary alarms for every type of change and to allow staff to focus on the important alarms.
8. Provide critical staff with secondary means to communicate, such as SIM cards from third-party network operators.

[3] Xona Partners, "Assessment of Rogers Networks for Resiliency and Reliability Following the 8 July 2022 Outage – Executive Summary," July, 2024. See: https://crtc.gc.ca/eng/publications/reports/xona2024.htm

9. Simulate and practice network failure and outage scenarios to uncover deficiencies in the network architecture and the incident management process.

Key Takeaways

- The complexity of telecommunications networks is increasing, raising the risk of network failures leading to severe service outages.
- Network outages can severely affect essential services, including emergency calls, public safety communications, and access to critical services such as payment systems, demonstrating the critical dependency on telecommunications networks.
- Human error has emerged as a leading cause in recent catastrophic network outages, highlighting the importance of configuration management, incident management procedures, and rigorous laboratory tests.
- Regulators are increasingly concerned about network availability, emphasizing the importance of network resiliency, thorough testing, robust processes, and system redundancy to prevent future outages.
- Effective communication strategies are crucial for managing public and stakeholder perceptions during network outages.
- Establishing clear and comprehensive incident response plans, including regular drills and scenario planning, can improve the speed and effectiveness of outage recovery.
- Transparency and accountability in post-incident reviews can lead to valuable insights and improvements, building trust with customers and stakeholders.
- Integrating lessons learned from past outages into continuous improvement processes is essential for enhancing network robustness and reliability over time.
- Continuous monitoring and auditing of network performance and security can help preempt potential failures and identify vulnerabilities early.
- Proactive investment in network infrastructure and technology upgrades can enhance overall network resilience and reliability.
- Investors in telecommunications assets must consider network resiliency and reliability in their technical due diligence, alongside network performance and regulatory compliance.

About Xona Partners

Xona Partners (Xona) is a boutique advisory services firm specializing in technology, media, and telecommunications (TMT). Established in 2012 by a team of seasoned technologists, startup founders, managing directors in global ventures, and investment advisors, Xona leverages its founders' cross-functional expertise to offer a unique, multidisciplinary approach to technology and investment advisory services. Our clientele includes private equity and venture funds, technology corporations, regulators, and public sector organizations. We assist our clients with pre-investment due diligence, post-investment lifecycle management, and strategic technology management, helping them identify new revenue streams and navigate the complex landscape of the TMT sector.

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Mobile Infrastructure Capex: Permanent Weakening or Short-Term Decline?

Overview. Mobile infrastructure capital expenditures has declined significantly since the second quarter of 2023, following a wave of spending on 5G, and no recovery is yet in sight. While the mobile industry has faced such declines in the past, signs suggest that the current weakness could be longer and deeper than previous downturns. In this insight note, we explore the top five threats that could turn the current spending cycle into a long-term bear market for mobile infrastructure:

1. **Declining Mobile Traffic Growth**: Reduced growth in mobile traffic eases the pressure for network upgrades.
2. **Network Disaggregation**: Operators can selectively upgrade parts of the network, extending the lifecycle of existing equipment.
3. **Completed Investments in Physical Infrastructure**: Major investments in physical infrastructure are largely completed, leaving spending focused on incremental expansion.
4. **Delayed 6G Deployments**: 6G is not expected to become commercial with meaningful deployments for at least six more years.
5. **Financial Pressures**: Many operators face financial constraints that preclude large capex spending.

Peak Mobile Infrastructure Capex

Peak mobile infrastructure capex reached $195 billion in 2014, according to data from the GSMA Mobile Economy Report. This peak aligns with significant investments in 4G LTE networks, which began commercially launching in 2010.

We estimate that spending on LTE exceeded that for 5G in real terms over similar deployment phases. Total mobile capex during the first five years of the LTE deployment cycle (2010-2014) amounted to $1,120 billion in 2023 dollars. In comparison, spending on 5G over a similar five-year period since its first launch in 2019 is $1,004 billion in 2023 dollars.

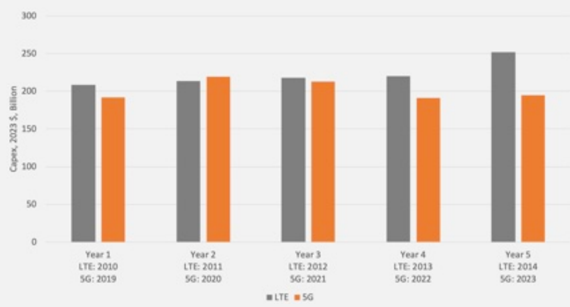

Figure 1 Mobile capex for the first 5 years of LTE and 5G lifecycles from the year of first commercial deployment. Values are adjusted to 2023 dollars.

Declining Mobile Traffic Growth. Growth in mobile traffic has been the main catalyst driving the deployment of new generations of mobile technologies. In the early 1990s, 2G was deployed following the success of analog 1G technologies, which could not sustain the increasing call volume due to the growth in mobile subscribers. Later, in 2009, 4G was deployed because 3G technologies failed to provide sufficient data rates as the Internet became mobile. Verizon was among the first to deploy LTE, migrating away from a 3G version of CDMA. AT&T, which had exclusivity on the iPhone released in 2007, had to migrate to LTE to inject capacity into its network, which was experiencing exponential traffic growth.

Today, the situation is very different. Mobile traffic growth has been declining, and traffic is plateauing. With the absence of new applications that can drive traffic on the networks, the pressure on operators to upgrade to a new technology eases.

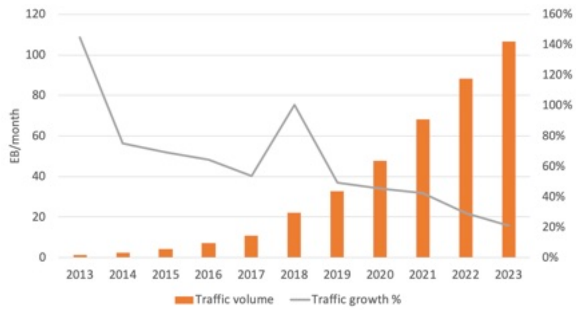

Figure 2 Mobile traffic including fixed wireless access. [Source: Ericsson Mobility Report]

Network Disaggregation. There are two types of disaggregation that have become dominant features in 5G: hardware-software disaggregation and functional disaggregation.

Hardware-Software Disaggregation (Network Virtualization). This type is prevalent in Operating and Business Support Systems (OSS/BSS) and the mobile core network. Virtualization allows operators to decouple the software from the hardware upgrade cycle, transforming part of the software-related expenditure into operational expenses. Meanwhile, capex spending on hardware can be fine-tuned and spread out over time. In contrast, original 4G network elements had an appliance-based architecture with tightly coupled hardware and software, resulting in larger lump-sum investments.

Functional Disaggregation. 5G has disaggregated both the core and the radio access network into multiple functions. For instance, the service-based architecture of the 5G core is divided into more than 12 functions, each of which can be independently deployed, scaled, and upgraded. Additionally, the 5G core separates the control plane from the user plane. This modular approach significantly contrasts with the monolithic architecture of the 4G core, which had fewer functions. Similarly, the 5G RAN is disaggregated into three functions (centralized, distributed, and radio units), with interfaces defined by industry alliances like the ORAN Alliance and the 3GPP.

Functional disaggregation allows operators to optimize cost and performance trade-offs based on the services offered by the network. As a result, operators can selectively target certain functions for upgrades, streamlining expenditure over time and smoothing the spending cycle in the future.

Completed Investments in Physical Infrastructure. Transport networks and towers are two critical physical infrastructures for mobile networks, both of which have consumed significant capex. We argue that substantial investments were made in both over the past decade, leaving future investments to be incremental.

Fiber Networks. Operators have consistently upgraded their transport networks with each generation of mobile technology. With 4G, the adoption of a flat-IP and a distributed RAN architecture supporting broadband data rates necessitated connecting more cell sites with fiber. This activity intersected with the trend of fixed-mobile convergence, allowing operators with fixed access businesses to leverage their fixed networks for mobile backhaul. Consequently, fiber penetration for mobile backhaul is high in most developed markets, especially urban areas with high capacity demands. Moreover, most expenditures on fiber networks go towards civil works and laying fiber cables. Operators can upgrade these cables' capacity by changing the electronics, making future technology upgrades more cost-effective.

Towers. While many MNOs have divested from towers, transferring expenses from capex to opex, many others still hold significant assets. The main drivers for tower deployment are network densification and coverage footprint expansion. However, network densification has not materialized as expected. Small cells are deployed to address capacity hotspots, but their numbers fall short of market analysts' expectations. Operators deployed 5G primarily to inject capacity using new wide-bandwidth mid-band spectrum and features like massive MIMO. Consequently, wireless networks have ample capacity in certain areas, prompting MNOs to launch bandwidth-consuming, low-margin fixed wireless access services. Moving forward, operators will still need to upgrade their network footprints, but the era of major cell site buildouts is behind us, leaving tower growth to be incremental. This trend is evident in the financials of specialized tower companies, which consistently seek new revenue growth models.

Future developments could impact capital expenditures. Network architecture evolves over time, and network functions need to be placed to meet desired service performance levels. For instance, integrating edge computing into mobile networks could drive additional capex. However, such changes typically occur over a relatively long timeframe, making it unlikely that re-architectures will drive significant capex in the short term.

Delayed 6G Deployments. Technology upgrades are catalysts for significant capex, and the 5G upgrade cycle has largely run its course in most developed markets. We estimate that meaningful commercial deployments of 6G will begin in 2031. This estimate is based on recent roadmap discussions at the 3GPP, which target no earlier than March 2029 for the completion of 6G standards activities. Commercial deployments typically require about 18 to 24 months for the ecosystem to mature, including silicon testing and validation, infrastructure deployment, and technology field trials, leading to the 2031 timeframe.

A Wave of Divestments and Consolidation

A new wave of divestments and consolidation is sweeping through the telecom industry as companies seek to improve financial performance, reduce debt, and enhance operational efficiency. These activities have focused on the following areas:

- *Divestment of Operating Companies in International Markets*: European service providers such as Vodafone and Telefonica have sold operations in non-core markets.
- *Divestment of Tower Assets*: This trend is evident across all continents, with recent examples including tower asset sales by US cable companies. The largest transactions include sales by Deutsche Telekom and AT&T.
- *Divestment of Spectrum Assets*: Telecom service providers regularly buy and sell spectrum assets. A recent example includes Comcast selling 600 MHz spectrum to T-Mobile.
- *Divestment of Data Centers*: Many telecom service providers, such as AT&T and Verizon, divested their data center holdings several years ago. Recently, Canadian telco Rogers announced plans to sell 9 of its 13 data centers to raise $1 billion.
- *Divestment of Other Non-Core Assets*: This includes various businesses within service providers' portfolios. For example, AT&T sold its ownership of WarnerMedia, and Verizon sold its media business, which includes Yahoo and AOL, to Apollo Global Management.
- *Market Exit*: Some regional telecom service providers have opted to change business models or sell the entire company. For instance, US Cellular sold its operating assets, including part of its spectrum, to T-Mobile while retaining tower assets to transform into an infrastructure service provider.

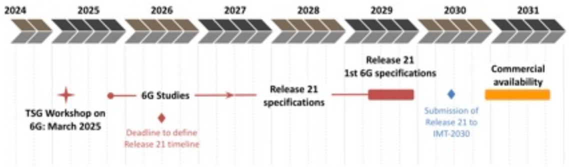

Figure 3 6G development roadmap. [Source: 3GPP, Xona Partners.]

Another trend for 6G is the industry's aim to avoid decoupling the radio access network (RAN) and the 6G core deployments. The goal is to complete specifications for both the RAN and the core network simultaneously, allowing for their concurrent deployment. This approach contrasts with 5G, which offered many migration choices for the core network, creating challenges for vendors who had to account for various deployment models and thus increasing development costs and timelines. The rapid deployment of 5G is often attributed to deploying a 5G RAN with a 4G core in what is called a non-standalone mode (NSA). Consequently, many current 5G deployments are not pure 5G but hybrid 4G-5G deployments. These setups enabled operators to deliver the promised speed of 5G without the differentiated services, such as network slicing, that pure 5G offers. By coupling the 6G RAN with the core—similar to all previous mobile technologies except 5G—the timeline for 6G availability will likely be extended.

Financial Pressures. The mobile industry faces intense competition, regulatory pressure, high expenditures for network upgrades and spectrum acquisition, and limited revenue growth potential. Recently, operators' debt loads ballooned as they borrowed to pay for spectrum and 5G network upgrades. In markets such as the US and Canada, record spending and spectrum valuations in auctions exceeded the amount spent on 5G deployments. The current high-interest-rate environment further exacerbates operators' financial performance and negatively impacts their valuations.

Reversing the Capex Trend

Various factors could combine to reverse the trend of declining capex. These interrelated factors include:

- *Regulatory requirements*, including compliance with new network reliability and resiliency measures, emergency services, cybersecurity, data management could impact capex upwards. Moreover, regulators strongly influence the price of spectrum licenses.
- *Densification* could disproportionally impact capex in the future. Future networks will increasingly rely on bands higher in the frequency spectrum, including bands between 6 GHz and 28 GHz. While densification has not yet contributed substantially to higher capex, that may change in the future, especially if new applications and devices reverse the trend of declining traffic growth.
- *Network footprint expansion* into indoor and rural deployments are harder to achieve with high frequency spectrum which works to increase capex, especially in case of regulatory pressure.
- *New applications and devices* could fundamentally impact traffic growth trends, much as the iPhone did when it was first introduced in 2007. Mobile video owes its dominance to the iPhone. This type of innovation and its impact on capex is hard to predict; but could be profound.
- *Rearchitecting the telecom network* to support new applications and use cases will add to capex. Examples include implementing edge computing to reduce latency or densifying the network to provide location and positioning services to support nascent applications like V2X.

Operator revenues have not seen a substantial or lasting boost from 5G. Any revenue increases from 5G have been short-lived due to intense competition capping profitability in many markets. Furthermore, regulatory pressure limits the prospects for generating additional revenues.

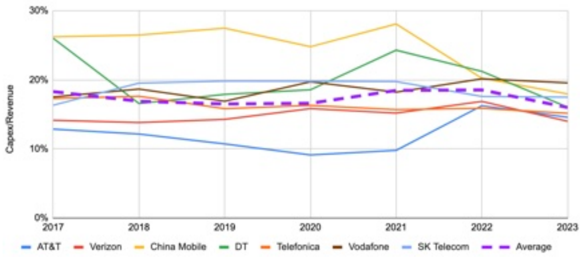

Figure 4 Capex as percent of revenue for select telecom service providers. [Source: Company information; Xona Partners.]

The combination of capped revenues and inflated liabilities has led to a series of mergers and asset divestments, including tower assets and entire regional operating companies. For example, Vodafone has been divesting some of its operating companies, and in the US, T-Mobile acquired US Cellular, the largest regional operator. Meanwhile, Verizon is considering selling more of its towers.

While MNOs generate good cash flows that allow them to pay dividends, the short-term environment is not conducive to investing, especially since the initial phase of 5G buildout is largely completed in most developed markets. Future upgrades, particularly in the core network or the implementation of 5G Advanced, are anticipated, but these are not projected to boost capex significantly, especially since operators can spread such investments over the medium term (2 to 5 years).

Key Takeaways

- Reduction in mobile network infrastructure capex is likely a secular trend driven by five fundamental factors. Already, 4G capex exceeds that of 5G on inflation adjusted basis. Moreover, we anticipate operators to amortize networks over longer time-frame.
- The five fundamental factors affecting mobile capex, include:
    - Declining Mobile Traffic Growth: Reduced growth in mobile traffic eases the pressure for network upgrades.
    - Network Disaggregation: Operators can selectively upgrade parts of the network, extending the lifecycle of existing equipment.
    - Completed Investments in Physical Infrastructure: Major investments in physical infrastructure, primarily fiber transport networks and towers, are largely completed, leaving spending focused on incremental expansion.
    - Delayed 6G Deployments: 6G is not expected to become commercial with meaningful deployments for at least six more years (2031 at the earliest).
    - Financial Pressures: Many operators face financial constraints that preclude large capex spending.
- To manage financial pressures, operators have pursued mergers and divested assets, including tower assets and regional operating companies. Examples include Vodafone's divestments and T-Mobile's acquisition of US Cellular.
- Upcoming Upgrades: Future upgrades, such as those in the core network or the implementation of 5G Advanced, are anticipated but are not expected to significantly increase capex. Operators can spread these investments over the medium term (2 to 5 years).
- A number of factors could reverse this downward trend in capex, including regulatory requirements, new applications and services, rearchitecting the mobile network to deliver on such applications and densification due to operating higher frequency bands.

About Xona Partners

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Navigating Precision: Evolving Trends in Positioning, Location and Timing Technologies

Overview. Several companies provide location and positioning services using a variety of technologies, including mobile network operators, satellite operators, and specialized location service providers. This Insight Note examines potential developments in this market segment in light of recent investments and technological advancements. It focuses on emerging use cases and potential requirements for location and positioning services to provide context for the future operating environment for both current service providers and new entrants.

The Commercial Context. Location-based services heavily rely on Global Navigation Satellite Systems (GNSS). One such example is the US Global Positioning System (GPS), which began operating in 1993 using a medium-earth orbit satellite constellation. Europe (Galileo), Russia (GLONASS), China (BeiDou), Japan (QZSS), and India (NavIC) operate their own constellations, providing similar services. GPS is just one of several location and positioning technologies, each with its own strengths and weaknesses (see the box titled Comparative Analysis of Location and Positioning Technologies).

The economic benefits of GPS in the private sector exceeded $1.3 trillion between 2000 and 2017, according to a study by RTI International sponsored by NIST. The telecommunications sector accounted for 51% of these benefits, followed by 24% for telematics services and 16% for location services provided by consumer devices and apps. The report estimates that a one-day GPS outage would result in approximately $1 billion in losses.

Use Cases for Positioning, Navigation and Timing (PNT) Services

Positioning refers to the capability to accurately determine one's location relative to a standardized geodetic system. Navigation involves determining both current and desired positions and making course corrections accordingly. Timing entails acquiring and maintaining precise time from a standardized source, globally.

A few uses cases help serve as examples of the above definitions:

Positioning:

- Logistics and transport tracking
- Enterprise asset tracking
- Lone worker and worker safety tracking
- Consumer tracking tags

Navigation:

- Consumer smartphones and wearable navigation and tracking applications
- Autonomous vehicle navigation
- Drone navigation

Timing:

- 5G core and radio-access network, including small cells, synchronization
- Data center synchronization and timestamping for banks and enterprise

The challenge with GPS services is that they are only available where there is a clear view of the sky; GPS is largely unavailable indoors and in areas with obstructed views. GPS signals can also be jammed, leading to errors in positioning, navigation, and timing. Additionally, in mobile network applications, GPS alone is often insufficient. For instance, the GPS receiver in the mobile device may

Comparative Analysis of Location and Positioning Technologies

Each positioning technology has distinct strengths and weaknesses, with key metrics such as service availability, location accuracy, and confidence interval being crucial. Particularly in industrial applications, the latency of location determination has become increasingly important. Addressing this need for reduced latency represents a significant goal for 5G positioning technologies.

Technology	Accuracy	Coverage	Latency	Advantages	Disadvantages
Global Positioning System (GPS)	3-5 meters (open sky); <1 meter with DGPS	Global	Low	Wide availability, high accuracy in outdoor environments	Limited indoor accuracy, dependent on satellite visibility
Wi-Fi Positioning System (WPS)	5-15 meters	Areas with Wi-Fi access points	Moderate	Effective indoors, leverages existing infrastructure	Variable accuracy, limited to areas with Wi-Fi coverage
Bluetooth Low Energy (BLE) Beacons	1-2 meters	Areas with beacon deployments	Low	High accuracy indoors, low power consumption	Requires beacon installation and maintenance, limited coverage
Ultra-Wideband (UWB)	Centimeter-level precision	UWB-enabled areas	Extremely low	Very high accuracy and reliability, suitable for real-time applications	Limited range and coverage, requires specialized hardware
5G NR Positioning	<1 meter horizontal, <3 meters vertical	Within 5G network coverage	Low	High accuracy, low latency, supports advanced applications like Industrial IoT	Dependent on 5G deployment and density, still evolving with ongoing standardization
Inertial Navigation Systems (INS)	Varies, can drift over time	Independent of external signals	Very low	Works without external signals, effective in environments where GPS is unavailable, very low latency	Accuracy degrades over time without external correction, often requires integration with other systems for optimal results

lose synchronization with the GPS satellite signals, the user may turn off location services, or the user may not authorize location sharing. To augment GPS, mobile technologies implement their own native location and positioning services.

5G-Based Positioning. 5G positioning and location technologies are the result of nearly three decades of advancements in mobile positioning. Initially driven by regulatory requirements for emergency services, these technologies have evolved to meet the needs of various industry verticals and use cases. To address these demands, 5G enhances positioning services through improved signaling schemes, robust solution architecture, and the implementation of diverse positioning techniques. For the first time, mobile technology could become a competitive commercial positioning system, offering mobile network operators new opportunities to provide innovative services.

While a comprehensive explanation of the technical details enabling 5G to function as a positioning solution is beyond our scope here, it's important to note that 5G distinguishes between various use cases (such as smartphones in commercial or industrial applications and IoT devices) and has established a roadmap to achieve 20 cm location accuracy for Industrial Internet of Things (IIoT) applications.

Table 1 5G NR location and positioning target requirements.

Location Requirements	Horizontal accuracy	Vertical accuracy	Latency
5G NR Release 16: Applicable to commercial use cases	• Outdoor: < 10 m for 80% of mobile devices • Indoor: < 3 m for 80% of mobile devices	• Outdoor: < 3 m for 80% of mobile devices • Indoor: < 3 m for 80% of mobile devices	• Outdoor: < 1 second end-to-end • Indoor: < 1 second end-to-end
5G NR Release 17: Applicable to industrial use cases and IIoT	• Industry use cases: < 1 m for 90% of devices • IIoT use cases: < 0.2 m for 90% of devices	• Industry use cases: < 3 m for 90% of devices • IIoT use cases: < 1 m for 90% of devices	• < 100 msec end-to-end latency • < 10 msec PHY latency

The Market for 5G Positioning. Several mobile network operators currently offer telematics and other location-based services utilizing GPS and 4G LTE positioning technology, specifically Real Time Kinematics over LTE Positioning Protocol Annex (RTK over LPPa), as an augmented GPS solution. Although 5G NR positioning technologies promise superior accuracy and precision, widespread deployment of 5G-based positioning services by operators has not yet materialized.

The delay in rolling out 5G NR positioning services stems from several factors. One reason is the ongoing delays in 5G deployment in regions like Europe. Additionally, many current 5G networks still rely on 4G LTE core infrastructure, which cannot support advanced 5G location technologies. Lastly, there are significant cost considerations related to network density, particularly in environments requiring additional cell sites to achieve the

NextNav in Focus

NextNav offers proprietary horizontal and vertical location services. It grabbed attention by raising ~$400 million through a merger with a special purpose acquisition company (SPAC) in October 2021. NextNav holds Location Management Service (LMS) licenses in the 900 MHz ISM band (902 – 928 MHz), which is shared with Federal users and FCC Part 18 and Part 15 devices.

In April 2024, NextNav petitioned the FCC to change the rules of the 900 MHz band to allow NextNav to operate a 5G network. Highlights of the requested changes include:

- Reconfigure the 900 MHz band to include a 15 MHz FDD slice consisting of 10 MHz in downlink and 5 MHz in uplink.
- Allow mobile services in addition to LMS (Part 27).
- Increase transmit power to a level similar to mobile networks (30 W ERP currently).

NextNav argues it wouldn't be financially viable to build a standalone terrestrial network for positioning and location services. However, the business case is positive if allowed to offer 5G services. To bolster its 5G positioning tech, NextNav acquired Nestwave, a pioneer in 5G positioning, for $19.3 million in October 2022.

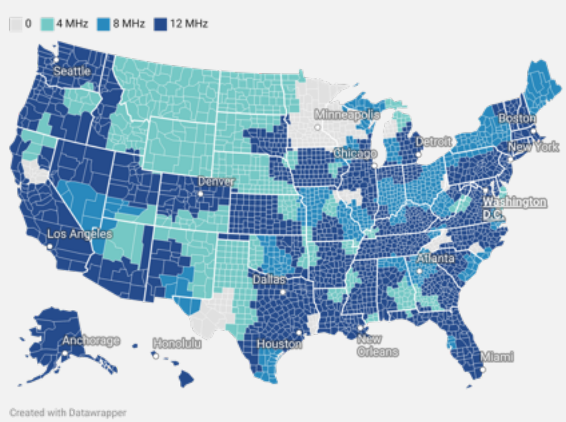

Figure 1 NextNav LMS license holdings post acquisition of Telesaurus and Skybridge licenses.

desired accuracy, impacting overall service cost and profitability.

Ultimately, providers of positioning and location services must carefully consider the needs of both current and emerging use cases. The table below outlines specific requirements for horizontal and vertical position accuracy across selected use cases. Additionally, providers must address other critical factors such as service availability, latency, time to first fix, and power consumption.

Table 2 Positioning requirements for various use cases. [Adapted from 3GPP TR 22.872]

Use Case	Outdoor / Indoor	Position Accuracy	
		Horizontal	Vertical
Bike Sharing	O	0.2 m / 2 m	
Augmented Reality	O	1-3 m	0.1 - 3 m
Wearables	O/I	2 m	1 - 3 m
Ad push	O/I	3 m	3 m
Person; medical equipment location in hospital	O/I	3 m	2 m
Patient location outside hospital	O/I	10 m	3 m
Trolley	O/I	0.5 m	1 - 3 m
Waste mgmt		3 m	
Emergency call	O/I	50 m	3 m
Accurate positioning for First responders	O/I	1 m	O: 0.3 m I: 2 m
Alerting nearby emergency responders	O/I	50 m	3 m
Emergency equipment location outside hospitals	O/I	10 m	3 m
Traffic monitoring & control	O	1 - 3 m	2.5 m
Asset tracking and mgmt	O	1 m; or 10 - 30 m	
UAV - Data analysis	O	0.1 m	0.1 m
UAV - Remote control	O	0.5 m	0.1 - 0.3 m

The Geopolitics of Location Services

Satellite navigation systems are at the heart of geopolitics. Control and ownership of these satellite constellations offer strategic advantages to their operators. Historically, the dominance of the U.S. in GPS has provided significant civilian and military benefits. In response, the EU and countries like China and Russia developed their own GNSS networks to reduce dependency on foreign systems and assert technological sovereignty.

The integration of positioning technologies into the broader digital infrastructure, including 5G networks and applications like autonomous vehicles further complicates the geopolitical landscape. Control over these technologies can influence economic alliances, trade agreements, and standards-setting bodies, shaping global technological norms and power dynamics. As nations continue to advance their capabilities in positioning technology, the geopolitics surrounding these systems will likely become increasingly complex, influencing global governance and security policies.

GNSS networks typically rely on medium-earth satellite constellations, which can efficiently provide services with a moderate number of satellites. However, several startups are planning to offer GNSS from low-earth orbit (LEO) constellations. The economic viability of these constellations is crucial, as they require a larger number of satellites to achieve global coverage and maintain service reliability.

Service	Number of Operational Satellites
GPS (US)	31
GLONASS (Russia)	24
Galileo (EU)	26
BeiDou (China)	35
QZSS (Japan)	7
NavIC (India)	9

Key Takeaways

- Each positioning technology exhibits distinct strengths and weaknesses, emphasizing critical metrics such as service availability, location accuracy, and confidence interval.
- Emerging applications are driving increased demand for additional requirements such as latency in location determination, time to first fix, and power consumption.
- Despite its robust positioning capabilities, 5G positioning services have yet to be fully embraced by mobile network operators, who continue to rely on 4G/LTE-based positioning services.
- Achieving high accuracy and availability with 5G positioning necessitates deploying a standalone 5G core network and additional cell sites in certain areas.
- While GPS provides outdoor ubiquity and acceptable accuracy, combining it with other positioning raises the profitability threshold for competing technologies.
- Providers of positioning and location services must assess requirements and market potential for emerging use cases, as these are critical factors influencing their profitability.

About Xona Partners

Xona Partners (Xona) is a boutique advisory services firm specializing in technology, media, and telecommunications (TMT). Established in 2012 by a team of seasoned technologists, startup founders, managing directors in global ventures, and investment advisors, Xona leverages its founders' cross-functional expertise to offer a unique, multidisciplinary approach to technology and investment advisory services. Our clientele includes private equity and venture funds, technology corporations, regulators, and public sector organizations. We assist our clients with pre-investment due diligence, post-investment lifecycle management, and strategic technology management, helping them identify new revenue streams and navigate the complex landscape of the TMT sector.

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Exploring New Opportunities in Active Mobile Infrastructure Sharing

Overview. The evolving landscape of the mobile industry is prompting various stakeholders to explore active mobile infrastructure sharing initiatives. Technological advancements, notably in Open RAN and network slicing, are driving this recent surge of interest in active infrastructure sharing. In this Insight Note, we outline several critical factors essential for evaluating and implementing such sharing models effectively.

Market Segmentation. It's essential to first define the market and deployment scenario, as there are diverse forms to active mobile infrastructure sharing, and the success of each hinges on the specific context of the market and deployment scenario. Important market segments to consider include:

- *Market Considerations*: Approval from national regulators is imperative for certain sharing arrangements, as they significantly impact cost structures and competitive positioning. Additionally, in some markets, mobile operators prefer an independent approach in selective or all types of deployments, rendering active sharing arrangements impractical. Understanding the regulatory and competitive landscape is crucial.
- *Deployment type*: Mobile infrastructure is deployed in both outdoor *and* indoor environments, each requiring distinct sharing mechanisms and arrangements.
- *Site characteristics*: Mobile infrastructure comprises macrocells (e.g., large towers and building rooftops) and small cells, where radio units are positioned a few meters above ground level.
- *Type of area*: Distinctions exist *between* urban and rural areas. Operators often lean towards infrastructure sharing in rural regions, where low subscriber density necessitates low infrastructure costs to reach financial breakeven.

Defining and understanding the market landscape is a pivotal initial phase since certain types of active sharing arrangements are not viable in practice.

Technology Game Changers!?

5G introduces two key technologies that significantly advance mobile infrastructure sharing capabilities.

Firstly, network slicing enables the creation of distinct virtual networks on the same physical mobile infrastructure. These slices offer performance guarantees and ensure that clients receive contracted Service Level Agreements (SLAs), instilling confidence and predictability for both operators and customers. Notably, network slicing requires a standalone (SA) 5G core.

Secondly, Open RAN aims to disaggregate the radio access network into modular blocks that interoperate via standard interfaces, fostering vendor diversity. While various architectures exist for these blocks, the primary focus lies on the interface between the radio unit (RU) and the distributed baseband unit (DU).

It's important to acknowledge that deployments of network slicing, SA cores and Open RAN have yet to meet initial analyst projections, attributed to factors beyond the scope of this Insight Note.

MOCN and MORAN Sharing

Multi-Operator Core Network (MOCN) and Multi-Operator Radio Access Network (MORAN) represent two prevalent active sharing schemes among network operators. Both models involve operators utilizing their own core networks while sharing the radio access network. However, they diverge significantly in their approach to spectrum utilization. While the physical assets are shared similarly in both schemes, the distinction lies in the allocation and management of spectrum resources.

In MOCN, operators pool and share their spectrum assets. Each operator configures RF carriers to broadcast distinct Public Land Mobile Network (PLMN) IDs as per their agreement. This setup enables an operator lacking spectrum to leverage the radio access network of another operator with available spectrum. While MOCN optimizes spectrum utilization by consolidating all spectrum assets, it necessitates collaboration among operators for configuration, service provisioning, and optimization.

In MORAN, RF carriers are configured to broadcast the distinct PLMN ID specific to each network operator, granting each operator autonomy over its frequency carriers. This setup enables operators to independently manage their frequency carriers, offering greater flexibility and logical independence compared to MOCN. With MORAN, operators benefit from physical sharing while maintaining some control over cell parameters and service provisioning, enhancing operational independence.

Elements	MORAN	MOCN	Notes
Core network	Separate	Separate	Separate cores allow each operator to provide customers with services according to their roadmap and objectives.
Backhaul / transport	Shared	Shared	Shared transport network saves costs.
Base stations: baseband units radios and antennas	Shared	Shared	Requires a single base station vendor to enable sharing of the radio access network elements, including the baseband units, radios and antennas. This is referred to as “active sharing” and saves costs. However, it ties the operators to a single vendor and roadmap. Operators would also not be able to leverage the RAN performance to differentiate services. Operators would need to collaborate closely for operation and maintenance.
Spectrum	Separate	Shared	• MORAN allows separate spectrum to enable differentiation and independence (two PLMN IDs). • MOCN makes better use of spectrum because operators pool spectrum
Configuration, performance, fault management	Separate	Shared	Shared configuration management requires close collaboration and commitment to single vendor roadmap/features. MOCN offers partially shared fault and performance management.

The Type of Sharing. Defining what to share is critically important and requires careful definition since it ultimately has consequences on the profitability.

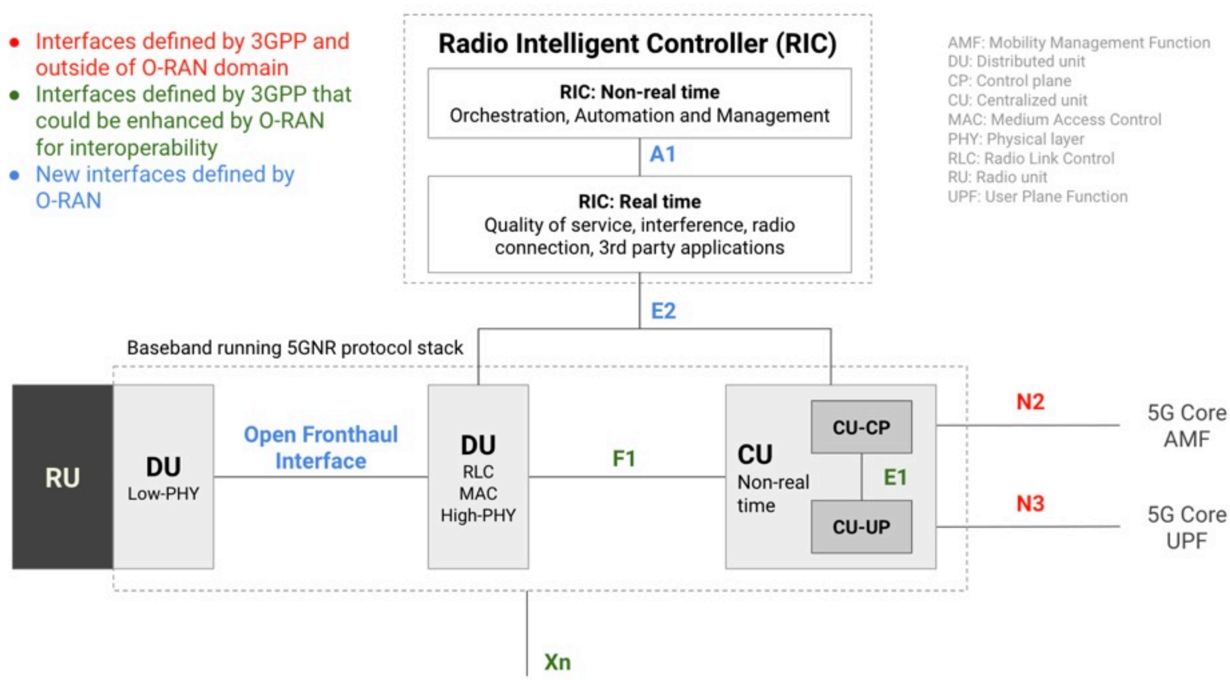
In this Insight Note, our focus lies in exploring emerging active sharing methodologies facilitated by Open RAN and network slicing, which go beyond conventional sharing models like MORAN and MOCN. One such model involves operators sharing the radio unit while preserving independent baseband modules. While we won't delve into the specifics of these new arrangements here, our aim is to outline key considerations for evaluating such innovative sharing models.

Critical Factors to Successful Sharing. To comprehensively characterize each active sharing scheme, it's imperative to assess technical, operational, market, and financial factors. These would encompass:

Alignment of frequency spectrum assets. This aspect is pivotal, particularly when the subject of sharing is a radio unit compliant with ORAN standards and specifications. Questions surrounding the type and quantity of frequency bands, as well as their positioning in the frequency spectrum, must be addressed. The allocation of frequency spectrum and bands significantly influences the cost of radios and directly impacts the business case. Additionally, power allocation is another crucial consideration. Radios are typically subject to specific power limits, which must be divided among the various operators, necessitating careful trade-offs.

Alignment of operator technology roadmap and network architecture. Operators must synchronize their technology roadmap and network architecture, encompassing both the radio access network and the core network.

Initially, operators must harmonize their migration between technologies, such as transitioning from 4G to 5G and beyond. Considerations also arise regarding the deployment of a 5G standalone core versus



Open RAN architecture disaggregates the radio access network functions to enable new deployment models.

the prevalent non-standalone architecture utilizing a 4G EPC to manage the 5G RAN. Notably, network slicing is only feasible with a 5G standalone core.

For instance, sharing a 5G base station in non-standalone mode necessitates utilizing the X2 interface between the 4G eNB anchor cell and the 5G gNB, requiring the use of the same vendor for both 4G and 5G networks. Additionally, careful consideration is warranted regarding the delivery of voice services in a shared network, such as VoLTE and VoNR implementation. Overall, network sharing in non-standalone mode is comparatively complex, emphasizing the importance of aligning operator roadmaps for network architecture and applications/features, such as standalone migration and voice service delivery.

Furthermore, coordination among service providers and their equipment vendors is imperative to ensure interoperability across all interfaces throughout the network's lifecycle. Different frequency bands necessitate various architectures for supporting features like massive MIMO and beamforming, contingent upon both the radio unit and the baseband units.

Lastly, some sharing schemes mandate user devices to support specific features available in newer versions of standards. The impact of user devices is another important aspect when planning network sharing schemes.

Considering the myriad issues related to architecture and roadmap, establishing a common understanding of network architecture and supported feature roadmap is indispensable for the success of new active sharing models.

Maturity of interoperable interfaces. The success of new active sharing models hinges on standard-based interoperable interfaces within the radio access network, as defined by the 3GPP and the ORAN Alliance. It is imperative that operators align on the interfaces governing their agreement and the maturity of these interfaces. Additionally, mechanisms must be established to evolve over time to incorporate new features, emphasizing the critical importance of testing and verification processes.

Market assessment. This becomes crucial when a third party seeks to provide shared active infrastructure as a service. In such instances, the sharing context must encompass all competitive forces and dynamics among network operators, in addition to the market factors discussed earlier.

Operational assessment. Numerous network sharing agreements encountered challenges during the operational phase, often stemming from divergent priorities among operators across various dimensions. As a remedy, many agreements led to operators establishing joint ventures to oversee their shared active infrastructure. However, some of the new sharing models introduce an independent third party, necessitating a clear delineation of responsibilities for the shared infrastructure matrix.

Business model and financial assessment. Determining whether a third party should take on the role of operating and maintaining shared infrastructure is a matter tied to operational efficiency. Such a third party would assume specific liabilities as the owner-operator of the shared infrastructure. Therefore, establishing a compensation scheme and business model is crucial to ensure profitability.

Expanding Opportunities. It is worth noting a few use cases that, while not classified as active network sharing, yield similar outcomes. Private Virtual Network Operator (PVNO) serve as an example. In an MVPN setup, an enterprise (or virtual service provider) manages its core network, and mobile devices roam on a service provider network beyond the enterprise's coverage area. Comparable approaches have been utilized to extend coverage to remote areas, often in partnership with local organizations responsible for deploying the radio access network.

Key Takeaways

- Technological advancements, notably in network slicing and Open RAN, are driving a recent surge of interest in active infrastructure sharing.
- The new models offer the flexibility to share mobile infrastructure across diverse interfaces departing from conventional models such as MORAN and MOCN.
- Successful adoption of emerging infrastructure sharing models hinges on meticulous coordination across various dimensions. These encompass regulatory approvals, frequency spectrum coordination, technology roadmaps, network architectures, operational processes, interface maturity and interoperability, and the financial business case.
- The evolving landscape of mobile network architecture opens up novel opportunities for infrastructure sharing beyond traditional paradigms, exemplified by mobile virtual private networks.

Mapping the Road Towards 6G

Overview. Recent announcements from both the ITU-R and 3GPP provide valuable insights into the roadmap for the emergence of 6G technology. Based on historical norms, we anticipate meaningful commercial 6G deployments to commence around 2031. While the requirements and specifications for 6G are yet to be defined, this Insight Note delves into the pivotal factors shaping the definition of 6G.

Roadmap to 6G. The 3GPP, the standard body responsible for defining the requirements and features for 6G, has yet to commit to a firm roadmap. However, it has provided certain dates for significant 6G milestones, allowing us to visualize the roadmap to commercial deployments.

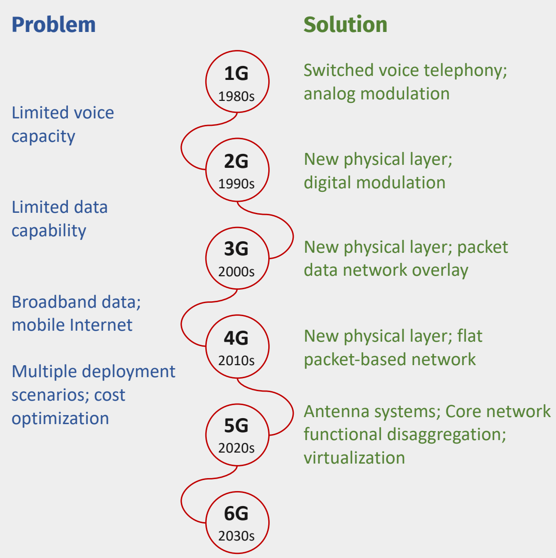
To provide context for the 6G roadmap, it's worth noting that as of the time of writing this note, the 3GPP is in the process of finalizing specifications for Release 18, scheduled for June 2024. Release 18, along with Releases 19 and 20, are part of the 5G Advanced technology. Development of Release 19 specifications is currently ongoing, with a target completion date in December 2025. Work on Release 20 is expected to commence in mid-2025, with an anticipated completion date in June 2027.

6G is slated for Release 21. However, before work commences, several activities need completion. The 3GPP will initiate its work on 6G by hosting a workshop on March 11th and 12th, 2025. This will be followed by studies and analyses planned to coincide with the development of Release 20. These studies will provide the foundation upon which specifications could be developed in Release 21. 3GPP anticipates defining the timeline for Release 21 by June 2026. Consequently, much

Why 6G?!

Successive mobile technologies introduce new solutions to improve the performance and fix challenges encountered in a prior generation. 5G solved many of the shortcoming in LTE such as introducing efficient massive MIMO technology in mid-band spectrum and disaggregating the core network into virtualized functions to optimize cost and performance. However, there are many areas for improvement, which include:

- 5G provides multiple core network deployment options, which slowed down the implementation of standalone 5G core.
- Dynamic spectrum sharing mode was plagued with interference issues.
- Rising concerns for network reliability, resiliency and service assurance.
- Demands for greater energy efficiency and reduction in power consumption.
- Increasing need for capacity and expansion into upper mid-bands (6-13 GHz).
- Standardization of additional interfaces.
- Expanding the use of AI/ML in network operations.
- Integration of satellite networks.



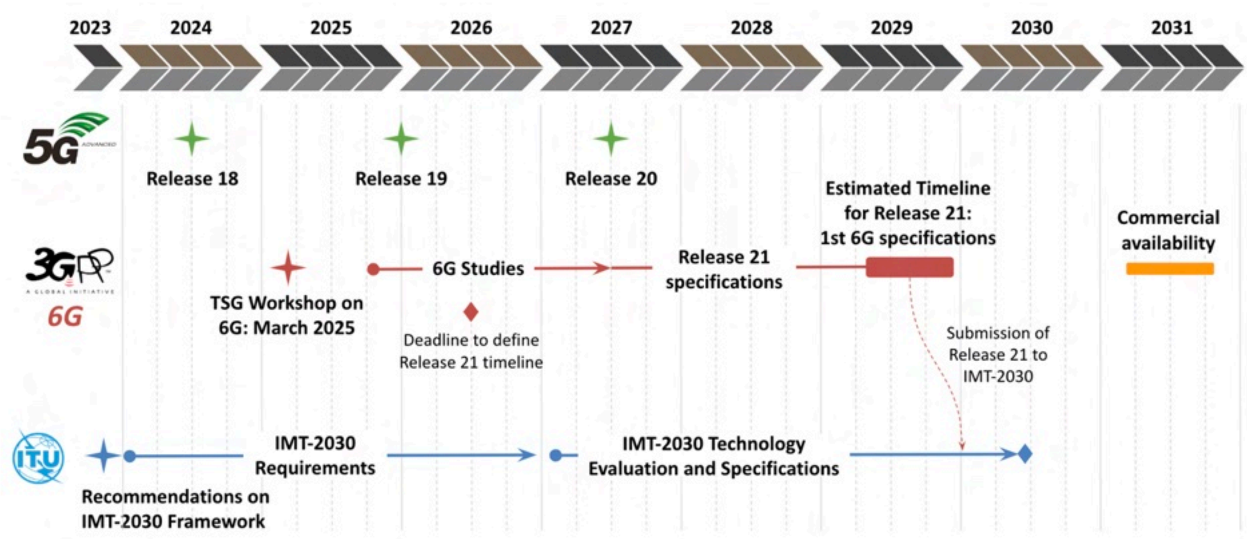


Figure 1 The roadmap to 6G mobile technology.

of 2028 will be dedicated to developing Release 21 specifications for 6G, expected to be completed no earlier than March 2029.

The 3GPP timeline must account for the schedule of IMT-2030 outlined by the ITU-R (refer to "6G Intersection with IMT-2030" in the box). The ITU-R will be formulating requirements for IMT-2030 until the end of 2026. Subsequently, it will begin accepting candidate radio interface technologies for evaluation starting in February 2027. The submission window for candidates closes by February 2029. Development of IMT-2030 specifications is slated to commence in mid-2029, with a target completion set for Working Party 5D Meeting #63 in June 2030. Therefore, Release 21 needs to be finalized before 2030. It's important to note that IMT-2030 only addresses radio aspects, while 3GPP will be tasked with defining specifications for the end-to-end network.

Typically, it takes approximately two years following the completion of a 3GPP release for the ecosystem to provide silicon for infrastructure and user devices, as well as for operator to test and trial the technology. This implies that the first commercial network may not be operational before mid-2031, assuming Release 21 is finalized by mid-2029.

The Geopolitics of 6G

In February 2024, the governments of the United States, UK, Canada, France, Japan, Korea, and several others issued a joint statement endorsing principles for 6G. These principles emphasize trusted technology for national security, resiliency, open and interoperable innovation, and energy efficiency. This announcement underscores the potential for increased government involvement in the standardization effort, particularly as tensions between the US and China escalate.

While the standardization process for 6G will undoubtedly involve competing visions backed by various technologies and intellectual property rights, the industry has historically achieved consensus resolutions for 4G/LTE and 5G. However, the path forward for 6G is less clear, with standardization scheduled to commence in approximately three years amidst rising global tensions.

It is worth recalling that the world unified around a single standard in LTE, which became commercially available in 2010. It would be unfortunate to regress to a previous era of fragmentation.

Expectations for 6G. 6G is anticipated to capitalize on the technological progress achieved in 5G, while also drawing upon advancements in other domains such as cloud technologies, semiconductor fabrication, computing and processing engines, and artificial intelligence, among others.

We spotlight several key development areas for 6G, recognizing that space constraints limit our ability to comprehensively cite all advancements.

Physical layer waveform. The multi-carrier Orthogonal Frequency Division Multiple Access (OFDMA) used in the 4G downlink path proved to be efficient. Consequently, its use was extended in 5G to the uplink path while further optimizing the efficiency of the downlink path. There are additional contending physical layers for use in 6G, for instance a variant of multi-carrier access technology, including OFDMA. The use of such a waveform will need to accommodate existing 4G and 5G networks. However, there is more liberty to implement a new physical layer in high frequency bands which will leverage advancements in silicon to reduce the cost of processing and improve power efficiency.

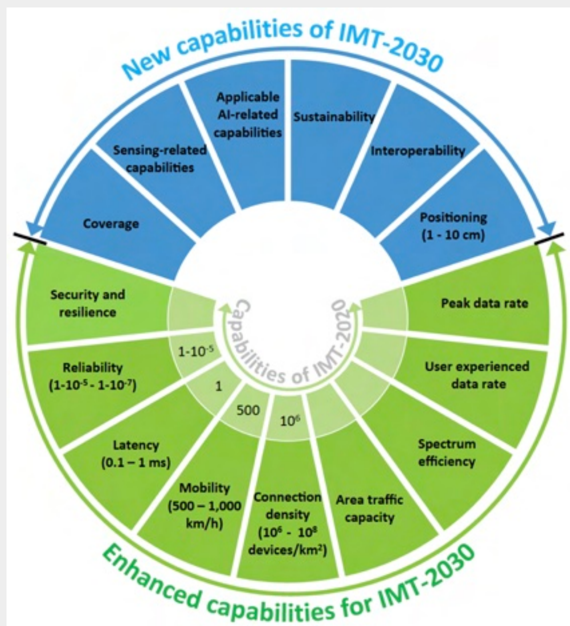
Channel coding. 6G will further seek to push the boundary of spectral efficiency by using more powerful low-power coding techniques.

Advanced antenna systems. Scalability of Multiple-Input Multiple-Output (MIMO) systems were critical to enabling 5G provide giga-bit-scale performance. The use of MIMO antennas will be further expanded in 6G especially in the higher frequency spectrum bands (e.g. 6 – 12 GHz) where much larger number of elements and transceivers will be used to further enhance capacity. Such antenna systems would support greater use of beamforming and lead to improved uplink and FDD mode performance. Additionally, 6G will seek to define implementations of

6G Intersection with IMT-2030

In November 2023, The ITU Radiocommunication Assembly unveiled the framework and objectives for IMT-2030 (ITU-R M.21602). The framework outlines trends, usage scenarios and capabilities for IMT-2030, with strong emphasis on sustainability, security, resiliency, and bridging the digital divide.

IMT-2030 expands upon the existing IMT-2020 framework by introducing three additional usage scenarios. These include ubiquitous connectivity, which integrates satellite connectivity, artificial intelligence, and communications, as well as integrated sensing and communications. These scenarios supplement the existing categories of enhanced mobile broadband, massive machine-type communications, and ultra-reliable and low latency services.



Source: ITU-R M21.602

The target capabilities outlined for IMT-2030 serve as points for research and investigation. These goals are provisional and subject to modification as practical and operational factors are considered. IMT-2030 also recognizes that these requirements could potentially be met by enhancing the existing IMT framework.

network-level MIMO systems which while available in 4G and 5G, they proved practically expensive to implement.

New frequency bands. Frequency bands in the 4-13 GHz range are expected to become available in the future for mobile communications. Additionally, bands in the 24-49 GHz are already available for 5G in many markets, albeit limited propagation characteristics. 6G is likely to target improving performance in these bands leveraging improvements in the waveform, coding, modulation and antenna systems.

In addition to new frequency bands, 6G would address different spectrum regimes, for instance static or dynamic spectrum sharing in the same geographic location. Such requirements will require an intelligent radio resource control function, where artificial intelligence/machine learning could play a role. Note that the impetus for sharing spectrum is not only for improving spectrum utilization, but it is also a mean of enabling new services such as direct-to-cell satellite communications.

Integration of satellite networks. Non-terrestrial networks are a relatively late entrant into 3GPP specifications starting in Release 17 onwards. 6G will take a wholistic approach to satellite communications which would be accounted for into the technology from the start.

Improve interworking with Wi-Fi. The convergence of cellular and Wi-Fi networks began with LTE. 6G is expected to facilitate even greater interworking between the cellular and Wi-Fi networks.

Leveraging AI. There are different use cases for AI in 5G network which primarily aim to optimize performance, reduce operational costs and improve network efficiency. While AI is an add-on to 5G, 6G is poised to leverage the learnings from 5G and embed AI into its framework, although this won't be a standard play.

Core network evolution. 5G introduced multiple core migration roadmap options for operators, which slowed down the deployment of standalone 5G core options. While it is premature to predict the exact evolution of the core network, it is anticipated that the industry will move away from such an approach. Overall, we anticipate the industry to: 1. Align 6G core products with advancements in cloud-native deployments and corresponding CICD and automation solutions; 2. Integrate some Core and RAN control plane functions; 3. Harmonize service layer functions and incorporate device/RAN/core compute functions into the same service architecture; and 4. Embed AI functions within the core network.

There are several other critical issues to address in the future, including the evolution of Operation Support Systems and Business Support Systems (OSS/BSS), as well as interoperability between 5G and 6G and the migration from 5G to 6G.

Key Takeaways

- The 3GPP standards setting body and ITU-R body have published preliminary dates for the process to develop and standardize 6G technology for IMT-2030.
- 6G will be part of 3GPP Release 21 which should be completed no earlier than March 2029. This means commercial deployments could be in 2031 by accounting for a 2-year cadence for availability of silicon and completion of technology field tests and trials.
- 6G will push operations higher into the upper mid-band spectrum (6 – 13 GHz) and provide fixes to the shortcomings of 5G.
- IMT-2030 aims to address sustainability, security, resiliency, and the digital divide, while expanding usage scenarios to include ubiquitous connectivity, integrated sensing, and communications. These objectives are largely shared in the ecosystem for the 6G technology.
- Despite the technological advancements enabling new use cases, the lingering question persists: will 6G act as a catalyst for mobile network operators to augment their revenues with new use cases?

About Xona Partners

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