XONA PARTNERS

Telecom & Digital Infrastructure Technology and Investment Trends

A look ahead into 2024

December 12, 2023

Preface

As we look ahead to 2024, we thought to take stock of developments in telecom, cloud and digital infrastructure markets in 2023.

In our similar note recapping 2022, we said that "*the changing economic environment will lead to deeper questioning of the business case viability for some of these technologies, along with the implications of geopolitical trends and the potential divergence of standards for some of key upcoming technologies.*"

As we stand at the end of 2023, this assessment was largely correct. Investment in telecom infrastructure dropped, while that in cloud infrastructure remained resilient even if the final tally comes below the record registered in 2022.

Yet, we see that 2023 was the year of missed predictions. A widely anticipated recession for the US market did not materialize, although some countries in Europe are in a mild recession and China's growth rate is low enough to be considered pseudo-recessionary. The US stock market, as measured by the S&P Index, is near it's all time high. However, market valuation is primarily driven by the Magnificent Seven stocks which account for over 70% of the S&P's gain this year. A large part of the driver for these 7 companies (Apple, Microsoft, Nvidia, Alphabet, Amazon, Tesla and Meta) is artificial intelligence (AI) which is reminiscent of the dotcom bubble.

Market interest in AI fueled interest in the data center segment at different levels, such as:

- Suitability of brownfield data centers to host AI workloads, and the type or feasibility of upgrades needed to host AI workloads. This primarily focused on increased power densities and cooling architectures in the first order.
- The need for edge computing data centers where investors were interested in understanding the potential of AI applications and their requirements, for both AI learning and inference.
- Cooling technologies, such as liquid cooling, especially in the context of increasing rack power density associated with ever higher power consuming graphic processing units used in AI applications.

While AI kept interest in the data center segment vibrant, the telecom segment experienced different dynamics. Starting in the second quarter of 2023, the investments spigots were turned off quickly as service providers cut infrastructure spending sharply, leading to a significant drop in vendors' revenue (e.g. Ericsson saw a 60% decline in North American network sales). Compensating for this shortfall in private sector spending is government stimulus, such as the Broadband Equity, Access, and Deployment (BEAD) program in the United States, and similar programs in Canada and Europe.

Our team has been privileged to participate in several projects at the cutting edge of data center and telecom network infrastructure. To mention a few:

- Completed an assessment for the Canadian telecom regulator of the July 2022 Rogers network outage in Canada, which affected over 12 million subscribers.
- Advised on the planning of 5G private wireless networks. A particular one of interest was for a nuclear power plant.

- Advised a tower company and neutral host service provider in evaluating its growth options and strategies.
- Advised on the assessment and planning of LEO satellite constellations including broadband services and direct-to-device services.
- Partnered with various stakeholders to assess the impact of AI developments on data centers, cloud, connectivity and cybersecurity evolution strategies.
- Led various strategy workshops assessing the geopolitical impacts on the digital infrastructure value chain, including the compute and storage chipsets, networking, data and cybersecurity solutions as well as mobile, satellite and submarine networks.

During 2023 we published a selection of Insight notes on some of the prominent topics where our team participated in servicing clients, of which we note:

The Trials and Tribulations of 4G/5G Neutral Hosts. While tower hosting business model proved successful, models for fiber and small cell sharing generated low returns on investments, particularly in the United States. Infrastructure services companies need to carefully evaluate neutral hosting approaches in the context of their specific markets from different dimensions: regulatory, technical, financial and competitive among others.

Telecom Cloud Platforms. The extension of the public cloud to telecom networks is one of the most important technology trends with far reaching consequences for both cloud providers and telcos. Telco-Cloud providers tie-up facilitates the latter to access the network edge for proximity to end-users. Such tie-ups also present telcos with a myriad of options on how to use the public clouds, each with a corresponding model to evaluate against a lengthy criteria of requirements, such as vendor lock-in, data privacy, cybersecurity, and performance and resiliency. The challenge lies in assessing long-term juxtaposition of telcos and cloud providers which is one reason for the difficult decision set facing telcos today.

Edge Computing. Edge computing is one of these concepts that has in it something for everyone: cloud service providers, telcos, infrastructure service providers and enterprises just to mention a few categories of players in a vast ecosystem. A few of the companies that entered this space over the past few years have either failed or had to change their business plans. This makes it critical to conduct careful technical due diligence of the connectivity architecture for edge data centers; and commercial due diligence on the applications that will run on edge data centers, many of which is still in an evolutionary stage.

The State of Millimeter Wave for Mobile and Fixed Wireless Access. 5G extended the operation of mobile access networks into millimeter wave (mmWave) bands (24.25 – 71 GHz). We find that the prospects for mmWave are pushed further into the future to be part of 6G and satellite-borne mobile networks – where advances in semiconductors will lead to greater signal processing capabilities, thus contributing to improved cost/benefit tradeoffs.

Enabling Direct-to-Handset Satellite Connectivity. Direct-to-handset satellite services proposed by the likes of Lynk Global, AST SpaceMobile and SpaceX are bold commercial endeavors that lack the appropriate regulatory framework for sharing spectrum between mobile network operators and satellite service providers. The FCC Supplementary Coverage from Space is the first framework for regulating direct-to-handset satellite services allowing satellite operators to communicate with mobile devices over MNO spectrum. Other regulators need to follow suite: these constellations would certainly fail without access to a global market.

Looking forward to 2024, we anticipate that many of the above topics will remain of interest. Some will have added significance in the context of technology decoupling due to rising global geopolitical tensions. These areas include:

- AI platforms including the entire value chain from semiconductors to edge cloud infrastructure to Large Language Model platforms.
- Space Internet where China will drive for parity with US and European-based constellations.
- Quantum technology for both computing and cybersecurity applications.
- Telecom standards which are at high risk of bifurcation into two to serve China and Western block countries.
- Resiliency of wireline, wireless and cloud infrastructures, given their increasing strategic importance to the sovereignty and economic development of nations.
- Sustainability of cloud and telecom infrastructure, especially in the context of AI and 5G.

In conclusion, we anticipate that both the economic landscape coupled with geopolitical tensions would be key influencers for investments in telecom, cloud and digital infrastructure assets in 2024. Disinflation in asset valuation would serve as a reminder to investors of the importance of appropriate technical and commercial due diligence to minimize the losses from bursting bubbles created by the hype cycles.

In This Edition

The Trials And Tribulations of Neutral Hosts: A Focus on Outdoor Small Cells

Overview. Elliott Management, an investment management firm, first pointed to the financial underperformance of Crown Castle's (CCI) fiber business in 2020 and reiterated that very recently, at the end of November 2023. CCI fiber business is driven in good part by a neutral host service for small cells. Elliott's argument for underperformance includes low uptake of small cells, high capital expenditures and low profitability in comparison with the tower business. This insight note dives into the small cell market to highlight aspects that governs their deployments. Note that we focus on outdoor small cells.; indoor small cells are not covered in this note.

The Context for Small Cell Hosting. The concept of hosting small cells evolved in the early 2010's with the first wave of the small cell hype cycle. It is an extension of the tower business, but with unique deployment characteristics that makes small cell hosting distinct.

By definition small cells cover a small area. They are deployed at low elevation above ground. Just like macrocells, small cells still need power and backhaul (fiber) to operate. For the model to scale, the capital costs have to be sufficiently low to enable the deployment model.

There are a number of factors that drive deployments costs, but for the purpose of shared networks, two critical ones are the density of small cells (the number of small cells that share the same fiber) and the number of tenants who will share the capital expenditures.

The Many Forms of Neutral Hosts

Neutral hosting is an umbrella term for a large number of models for sharing wireless network infrastructure. These models have evolved over time as wireless networks became increasingly more sophisticated. In fact, it perhaps deserves an Insight Note to address its different variants.

The earliest forms of network sharing included sharing passive elements such as towers and antenna systems, which is particularly relevant for indoor wireless systems. Later, operators began sharing active elements such as entire base stations (radio access network sharing). Different business models emerged which were supported by the evolution of technology standards to accommodate such business initiatives. These models include partnership, joint venture, and wholesale models.

Neutral host models have to be considered for specific geography and region within that geography. They also need to factor the technology in play, and the deployment model: for instance, urban or rural; outdoor or indoor; macro network or small cells.

Regulatory aspects play a large part in influencing neutral host models. This applies to policies related to competition among other considerations. Spectrum licensing and technology also factor highly.

Elliott makes the argument that the uptake of small cells falls below industry expectations and mobile network operators have little interest in sharing small cell infrastructure and prefer instead to build their own fiber. Next, we address the reasons for the slow uptake small cells.

Challenges in Small Cell Deployments. A number of challenges have prevented the mass deployment of small cells. In this note, we share our insider perspective with additional context to highlight these challenges. However, we first draw attention that while some challenges are inherent to the small cell model, other depend on the specific market and regulatory context.

- **Small cells networks are difficult to plan and operate.** To put this in plain English: small cells are a headache for RF network planners and operations engineers.

  The technical reason is that small cells create additional cell boundaries in the network which are liable to cause dropped calls and poor data service because of interference and poor handoffs at the boundaries. The more small cells, the longer the boundaries. This increases the cost to operate and maintain small cell networks, especially if they share the same spectrum with the macrocell layer.

- **Poor performance.** Networks that use the same spectrum for the macrocell and small cell layers suffer from interference due to the large power difference between the two layers. This was one of the main reasons that early generations of small cells, including first generation of LTE small cells, failed to gain traction among operators. [We refer to this as the first technology phase of small cells.]

  The industry developed technologies to mitigate the interference problem, but they proved to be unpractical. Specifically, the solutions included intermittently muting part of the macrocell layer transmissions (in time or frequency domain) to allow the small cell layer to operate without interference. This is equivalent to reducing capacity from the macrocell layer and assigning it to the small cell layer. The approach would only work if a large enough number of small cells is deployed. Of course, no operator was going to adopt small cells at the expense reducing the capacity of their macrocell networks. This marks the second technology phase of small cells.

  The third technology phase is linked to 5G which opened new frequency bands, particularly in millimeter wave spectrum. 5G provided operators the option to deploy small cells in their own spectrum, such as 28 GHz, to avoid the interference seen in in-band small cell deployments. Verizon is the best example of this approach: it deployed around 40,000 millimeter wave small cells. This approach solves the interference

CCI Foray into Small Cells

In addition to a portfolio of over 40,000 towers, CCI holds over 120,000 small cells and 85,000 miles of fiber (combined into the fiber segment). The fiber/small cell portfolio is the result of a long-term strategy that included a number of acquisitions.

Acquisition	Year	Value (Billions)	Fiber miles
NextG	2011	$1	4,600
Quanta	2015	$1	10,000
FiberNet	2016	$1.5	11,500
Wilcon	2017	$0.6	1,900
Lightower	2017	$7.1	32,000

The strategy contrasts with that of other infrastructure services companies, primarily American Tower and SBA Communications, who favored expanding their tower business internationally.

problem, but raises other issues related to the limited signal propagation.

- **Lack of low cost backhaul solutions.** Connecting small cells to the rest of the network is a technology and economic challenge. Several technologies were proposed since the early 2010's: wireless backhaul in non-line-of-site sub-6 GHz spectrum, millimeter wave or free-space optics are only a few to name. However, mobile network operators would require the same level of reliability and availability as that of the macrocell network. This leaves fiber as the only viable technology that can provide the service level performance operators needed in addition to meeting future capacity requirements.

  With small cells mainly deployed in urban areas for capacity, and laying fiber in such areas is costly, the business case for small cells became challenging.

- **Long and costly deployment cycle.** Operators have to deal with hundreds and potentially thousands of municipalities to secure permits to deploy small cells. The process itself proved to be long and costly. It is not unheard of for the process to last for a year or two and cost operators a similar amount to that of a macrocell site.

  The wireless industry lobbied regulators but success is limited because permits are the domain of local municipalities that are not governed by state or federal authorities. The alternative was to arrange for blanket lease agreements with entities that own public infrastructure such as utility companies. This approach works up to a certain extent: the tolerance for deviation in small cell location is very low. In other words, an exact match is needed for a light pole, or similar, and the desired location of the small cell.

- **Market-specific dynamics.** In addition to the above challenges, each market has its own dynamics that must be considered. For instance, infrastructure sharing is accepted in some markets (e.g. Europe and Asia-Pacific) while is has no traction in the United States where operators want

Is Small Cell Hosting a Bad Business?

Elliott argues that CCI's fiber business has destroyed value. It has been largely unproductive in generating profits, thus it should be divested.

CCI's fiber/small cells segment appropriates a higher proportion of capital expenditures to generate revenue, and it accounts for lower percentage of profits than the towers segment. Therefore, one could argue that fiber/small cells segment is a 'growth' business that includes a degree to risk and unpredictability.

CCI operates as a Real Estate Income Trust (REIT), which demands certain expectations of capital efficiency and predictability. Income trusts are most relevant to 'cash cow' businesses, such as tower infrastructure sharing. Therefore, the question is not whether fiber/small cells is a bad business, but whether the REIT structure is most appropriate for this business.

<table>
<tr><th colspan="2"></th><th>% of Site Rental Revenue</th><th>% of Total Gross Margin</th><th>Capex as % of Total Site Rental Revenue</th></tr>
<tr><td colspan="2">Tower segment</td><td>69.0%</td><td>72%</td><td>2.9%</td></tr>
<tr><td rowspan="2">Fiber segment</td><td>Fiber solutions</td><td>21.1%</td><td rowspan="2">28%</td><td rowspan="2">16.8%</td></tr>
<tr><td>Small cells</td><td>9.9%</td></tr>
<tr><td colspan="2">Total</td><td>100.0%</td><td>100%</td><td>19.8%</td></tr>
</table>

to deploy their own active wireless infrastructure. Therefore, the adoption of small cells need to consider various regional variations including spectrum, regulatory, economic, financial and other such considerations.

Observations on neutral host business models. The 2008 global financial crisis (GFC) was a turning point in the context of neutral hosts and network sharing. A maturing market with downward pressure on revenues, and the prospects of large capital expenditures to deploy LTE, which first came to market in 2009, provided the impetus for many operators to consider opportunities to reduce the cost of infrastructure buildout and operation. Technology standardization activities supported this direction by evolving techniques for radio access network sharing.

Small cells emerged around the time of the acceleration in the tower sharing business following the GFC. Unfortunately, the idea of multitenancy did not gain traction in fiber and small cell segments. For instance, CCI does not have multiple tenants for small cell sites; and US operators prefer to build their own fiber, led to a low number of small cells per mile of fiber (i.e. low density, which increases payback time and reduces profitability).

Looking ahead, the low interest rate regime that persisted since the GCF may well be of the past. Many macro-economists believe that geopolitics, supply chain decoupling and other factors are likely to result in higher inflation going forward than what was experienced over the last ~15 years. Operators and infrastructure service providers may not be able to finance their assets with as cheap a debt as they used to. This will pressure service providers to look for ways to reduce their expenses. As a result, projects that present a value further into the future would be negatively affected. News of Verizon suspending their small cell deployments come as no surprise in this context.

Yet, neutral hosting will remain an integral part of wireless infrastructure. Technology has evolved to enable a very rich mix of approaches of technology and business models. This means that one needs to find the right formula for neutral hosting given a sound evaluation of a number of dimensions: regulatory, technical, financial and competitive among others.

Key Takeaways

- Neutral host models need to be evaluated along a number of dimensions since their success will vary widely depending on the market. These dimensions include regulatory, competitive dynamics, business models, technical implementation, economic and financial considerations.
- Outdoor small cells went through different phases of technical evolutions to improve their performance. However, their uptake has been throttled by a number of inherent characteristics which we outlined in this Insight Note.
- It is critical to have a thorough and unbiased understanding of wireless technologies and their capabilities as well as the market and competitive dynamics to assess the prospects of success in evolving neutral hosting models.
- The neutral host business structure must be harmonized with the characteristics of the service. This includes a balance between the expectation of future revenues and the expenditures required to achieve these revenue targets.

About Xona Partners

Xona Partners (Xona) is a boutique advisory services firm specialized in technology, media and telecommunications. Xona was founded in 2012 by a team of seasoned technologists and startup founders, managing directors in global ventures, and investment advisors. Drawing on its founders' cross-functional expertise, Xona offers a unique multidisciplinary integrative technology and investment advisory service to private equity and venture funds, technology corporations, as well as regulators and public sector organizations. We help our clients in pre-investment due diligence, post investment lifecycle management, and strategic technology management to develop new sources of revenue.

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Insight Note

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Edge Computing: Has the Edge Turned Dull?

Overview. Edge computing is one of these foggy concepts that has in it something for everyone: cloud service providers (CSPs), telcos, and enterprises just to mention a few categories of players in a vast ecosystem. For the past 7 years – pinning the inflection point in Google Trends to 2016, although origins of edge computing date even earlier to CDN edge caching and mobile edge computing for mobile operators – the topic received much attention and funding from a host of corporate and financial investors. This has reinforced the hype around the edge while leaving many questions on market dynamics unanswered.

We now have better insights into the dynamics of the edge computing market. For one, in contrast to CSPs, telcos have failed at crystalizing an edge business, except in some regions of the world where telcos also offer cloud services at scale (directly or in partnership with CSPs). This is not unexpected: the birth of the telco edge is revolutionary concept that requires radical developments to realize, such as the softwarization of core and radio access networks, while the cloud edge is an evolutionary development with established fundamentals.

Latency is not the primary demand for CSP edge. This is contrary to what is often assumed, except for a tiny set of use cases. CSPs took a multipronged approach to edge computing. The first approach is offering enterprises with on-premise edge services. This included both hardware and software solutions that largely centered on IoT and AI applications. The aim is to facilitate the interworking of field devices with the cloud in order to grow cloud service revenue, while addressing some of the privacy and security concerns of enterprises.

What Makes For A Good Edge Data Center

There are many qualifications for edge data centers, such as proximity to the user and small size and low power. The basis for this view is the need for low latency which requires the placement of computing at the network access edge or even the device.

But we argue that physical proximity does not necessarily correlate with low latency. Moreover, low latency is not the primary driver of many, if not most, edge data centers today. Rather, data backhaul optimization and regulatory data localization, privacy and security that have been the critical factors in driving edge services.

This perspective leads to connectivity, and its underlying cost, being the most critical aspect for edge data centers. A good edge data center is one that is well connected with fastest connectivity to both the user and to the cloud. Therefore, the location of the edge is not the primary focus as long as connectivity offers the appropriate bandwidth, latency, and price. This is a critical point to consider for investors in edge data centers.

The second approach is pushing the cloud infrastructure closer to the customer by extending cloud availability zones in proximity of users and, consequently, edge data centers hosting the compute and storage infrastructure. In this case, the drivers include reducing the cost of backhaul, leveraging distributed storage and meeting requirements for data localization as mandated by national regulators. Latency comes into play for some specific use cases, such as AI inference once the AI models are trained, and hence, require proximity to the location where real-time data is generated and decisions are inferred. This type of edge occurs where there's already high demand for cloud services to make the return on investment worthwhile.

In either approach, we argue that latency in itself is not the critical driver for CSPs' edge growth. While latency is a by-product of the distributed cloud, it is not what drove CSPs to begin distributing their cloud, except for a nascent set of services. [CSPs do have latency targets, for example, Azure targets 25 msec. However, latency is not the sole and defining reason for the distributed cloud.]

The Latency-Driven Telco Edge. There are 3 use cases for the telco edge: 1. Provide differentiated consumer services; 2. Provide enterprise edge services; and 3. Host telco workloads that typically surround the 5G mobile core.

Much of the value proposition of the telco edge is centered enabling applications that require low latency [see Assessing Edge Data Centers: Meeting Application Requirements]. This is especially the case for mobile network operators who position 5G latency enhancements as being central to their value proposition. For them, the telco edge is contingent on one or more of the following:

1. The development of monetizable applications for consumers: a tricky proposition in the absence of bona fide applications with assured positive return on investment. We expect these applications to progressively develop, and this to be very incremental.
2. The deployment of enterprise private wireless networks where cost, complexity and spectrum availability are barriers to adoption. RoI validation will be fundamental based on specific contexts. We see this happening in some regions where spectrum and policy incentives exist in addition to relevant use cases.
3. The evolution of telco network functions into cloud-native workloads – a

The Dull Edge?

Over the past few years, a number of companies emerged to address the edge computing opportunity. Some have failed:

- MobiledgeX: The Deutsche Telekom funded entity was developing edge orchestration layer. Since the wireless industry outsourced edge services to cloud service providers, the company commercially failed. It was acquired and shut down by Google.
- EdgeGravity: The Ericsson company was building edge cloud infrastructure and services targeting network service providers. It folded in 2020.
- EdgeMicro: Founded in 2017, it raised $11m to deliver micro DCs with multiple connectivity at towers and other locations. Liquidated in 2021.

Other companies have changed their business models or product focus:

- American Tower launched its first 6 base-of-tower edge data centers in 2020 and has not added any since.
- Vapor IO focused on software management layer and interconnectivity instead of hardware and data center deployments which are significantly lagging initial plans.
- AlefEdge shifted its target market from service providers to enterprises planning for private networks.

We also find a number of companies that build containerised data centers announcing their intent to operate such units as edge data centers, but failed at doing so.

Nevertheless, we see rapid increase in edge applications, specifically those related to AI models where data locality and the cost and performance constraints of transporting learning and inference data from end users to cloud are significant. However, mapping these edge data applications to data centers is not necessarily synonymous with having data centers in close proximity to end users.

proposition that is: a. Primarily focused on virtualizing parts of the core network. It is too complex to realize full virtualization of all the core and radio access network elements where many elements will remain in hardware; and b. The failure of telcos in developing their own cloud infrastructure and relying on partnerships with cloud service providers. Here, AT&T makes a great case study: The company that made virtualization central to its technology strategy and launched several open source projects to this endeavor (CORD, ONAP, AKRAINO, etc.) decided at last to host its infrastructure on Microsoft Azure.

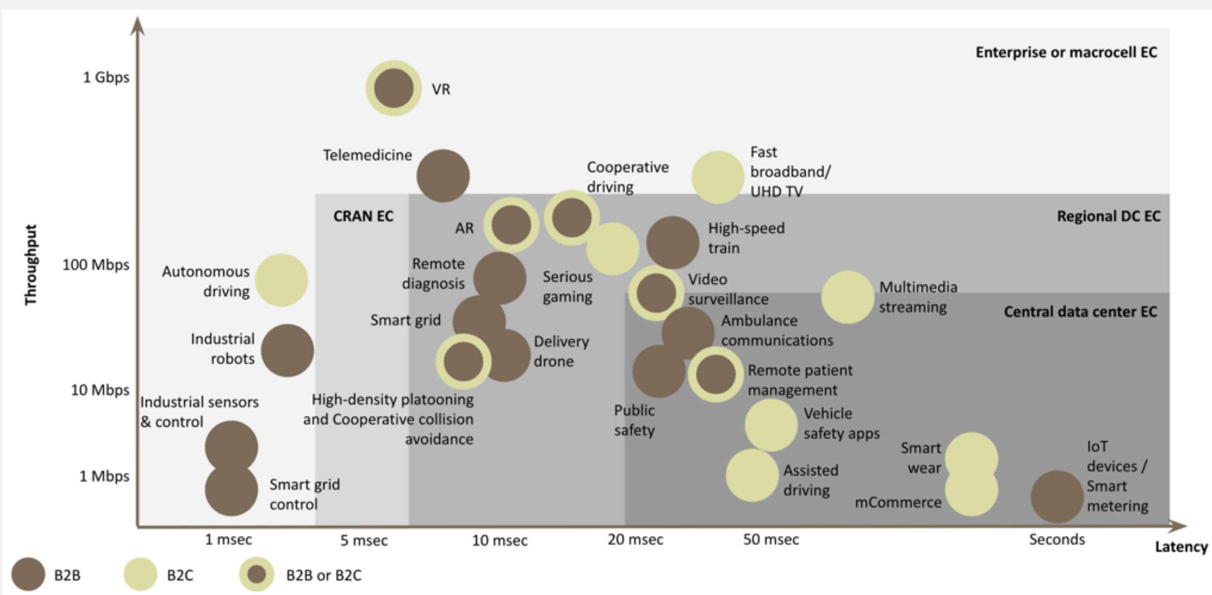
In light of the challenges, telcos decided to partner with CSPs as colocation service providers and resellers of CSP services (AWS Wavelength, Azure Edge Zones with Carrier, Google Distributed Cloud and Anthos for Telecom). This is a rather sound strategy that allows telcos to leverage their strength in providing connectivity services. Verizon, Vodafone, Orange, and other Tier 1 operators in primarily the most advanced 5G markets exemplify this approach.

Assessing Edge Data Centers: Meeting Application Requirements

Application vary in their requirements for latency. However, just as critical, is the variability in latency, or jitter. Wireless networks have traditionally offered high latency, on the order of 130 msec in 3G, and between 35 – 75 msec in LTE, depending on network architecture. 5G reduces latency following specific optimization of the air interface design and the core network architecture. 3GPP Releases 17 and 18 standardize the ultra-reliable low latency (URLLC) mode to bring further enhancements to 5G latency performance.

Latency is linked to physical proximity; however, physical proximity alone does not guaranty low latency. The network architecture, including data transport, affect the latency performance. This is a critical point in assessing the technical viability of edge computing data centers.

The business viability of edge data centers is dependent on the throughput and latency requirements of applications in the context of the edge data center costs. The challenge in this case is that applications have varying requirements, and many are still in the early evolutionary stage.



Application requirements for latency and throughput. [Source: Xona Partners]

Key Takeaways

- The cloud service provider edge is driven by requirements for data backhaul optimization and regulatory requirements for data localization, privacy and security. Latency is an important consideration, but it is not the sole factor. This makes the business case for CSP edge cloud development more predictable than the telecom edge cloud.
- The telecom cloud edge, especially for mobile network operators, is largely premised on application requirements for low latency. Many of these applications are in the early stages of technical development or in process of proving their market viability. This increases the risk for the telecom service providers who are opting to partner with CSPs to address the edge cloud opportunity.
- Careful technical due diligence of the connectivity architecture is critical to the success of edge data centers. Business due diligence requires factoring a view of the applications that will run on edge data centers, many of which is still in an evolutionary stage.

About Xona Partners

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Millimeter Wave Has Failed. Or Has It Really?

Overview. 5G extended the operation of mobile access networks into millimeter wave (mmWave) bands (24.25 – 71 GHz). mmWave access technology became a candidate for three different applications: mobile access, fixed wireless access and enterprise private wireless networks. It also put the mobile industry on a collision path with users of mmWave frequencies, primarily satellite service providers, and to a lesser extent backhaul applications. After more than half a decade of development, 5G mmWave has struggled to get market traction.

Not So Successful Auctions. Proponents of millimeter wave (mmWave) access technology loud its success by citing the number of completed auctions. Looking at the quality of these auctions reveals a contrasting conclusion: mmWave is struggling to gain the interest of mobile network operators. Except the United States and Australia, the demand for mmWave licenses is low; and operators are not willing to pay much beyond the reserve price. In one occasion – in Hong Kong - a free license was declined. A few regulators have delayed or scrapped auctioning mmWave.

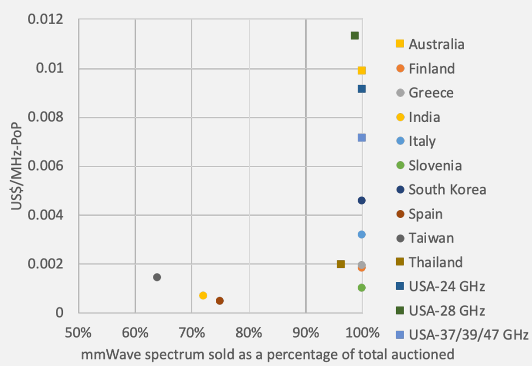
South Korea. The first country to auction mmWave spectrum for 5G access. The 2018 auction concluded at the reserve price of KRW 621 b (US$562 m). Each of Korea's 3 operators received 800 MHz between 26.5 – 28.9 GHz. The licenses were for a 5-year term and requires each operator to deploy 15,000 base stations by 2021.

In November 2022, The regulator revoked the licenses of KT and LG for missing the deployment requirements. SKT has until May 2023, instead of December, to deploy the 15,000 base stations or it will lose its license.

Performance of mmWave in Auctions

Regulators have much leverage in influencing the outcome of spectrum auctions. This is accomplished through different levers, such as the amount offered and spectrum cap, reserve pricing, deployment requirements among other. In effect, accentuating scarcity and increasing demand helps in raising prices.

The US market structure has provided for more competition over mmWave assets than other markets. The US leads in the number of bidders for spectrum assets and has consistently outperformed other markets in auction revenues.



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

India. The government sold 897 of 1254 licenses between 24.25 – 27.5 GHz in the 2022 auction accounting for an average 2055 MHz or 72% of auctioned mmWave spectrum. The proceeds of US$1.83 b fell short of the US$2.51 b aggregate reserve price.

Brazil. 3200 MHz between 24.3 – 27.5 GHz were part of the 2021 multiband auction. 95% of the unsold licenses in the auction were for mmWave. Only 5 of 10 20-year national licenses (200 MHz/license) were acquired by

Claro and Telefonica. TIM opted for 1 10-year license in addition to a few regional licenses. One of the regional winners backed out of their commitment after the auction concluded.

Spain. The auction concluded in December 2022 fetching €36.2 m – the same as the reserve price. Only 1800 MHz of 2400 MHz nation-wide spectrum, and 1 of 38 regional licenses were acquired. Telefonica secured the 1 GHz maximum, while Vodafone and Orange acquired 400 MHz each, well short of the 1 GHz cap.

Hong Kong. After an earlier attempt to auction 26 GHz spectrum, OFCA assigned three 400 MHz licenses between 26.55 – 27.75 GHz to SmarTone, China Mobile and HKT at no charge. Despite being offered a licence, Hutchinson did not see a value in having one.

Australia. The outcome of the 2021 26 GHz auction could be considered a success with 358 of 360 lots sold fetching A$647 m exceeding the reserve price of A$202 m.

United States. The FCC held 3 auctions for mmWave frequencies in 2019 and 2020, including 28 GHz (Auction 101), 24 GHz (Auction 102) and 37/39/47 GHz (Auction 103). All three auctions were competitive, fetching far over the starting price while selling most of the inventory:

- Auction 101: $702.6 m (starting price: $40.7 m); 107 of 3072 licenses unsold.
- Auction 102: $2 b (starting price: $293.5 m); 5 of 2909 licenses unsold.
- Auction 103: $7.6 b (starting price: $924 m); 2 of 14,144 licenses unsold.

US auctions have a relatively large number of bidders which drives prices higher. This is unlike other countries where the number of bidders is relatively small.

Singapore. In November 2020, IMDA issued 3x 800 MHz licenses in 26/28 GHz bands to Singtel, Starhub and M1 for capacity hotspot deployments. TPG also secured 2x 400 MHz licenses in 26 GHz and 29 GHz. The operators will pay an annual fee for 15 years.

Other countries. Several European countries have auctioned 26 GHz spectrum, including Italy, Denmark, Slovenia, Greece and Finland. These auctions concluded largely at the reserve price.

In Asia, Taiwan sold 16 of 25 licenses at the reserve price. Thailand sold 26 of 27 licenses at a premium to the reserve price, which is considered a success.

Japan's MIC allocated 4x 400 MHz mmWave licenses between 27 GHz – 29.1 GHz to its 4 MNOs on the basis of deployment and investment commitments. Therefore, the

Millimeter Wave in 5G Standards

5G defines two frequency ranges:

- FR1: "sub 6 GHz" between 410 MHz – 7125 MHz.
- FR2: "mmWave" between 24.25 GHz – 71 GHz.

The division into two ranges is necessary because of different technical requirements and specifications.

Each range is divided into different bands in order to streamline and harmonize the operation of equipment (base stations and user devices).

GPP FR2 frequency bands.

Band	Range (GHz)	ƒ (GHz)	Common name
n257	26.50 – 29.50	28	LMDS
n258	24.25 – 27.50	26	K-band
n259	39.50 – 43.50	41	V-band
n260	37.00 – 40.00	39	Ka-band
n261	27.50 – 28.35	28	Ka-band
n262	47.20 – 48.20	47	V-band
n263	57.00 – 71.00	60	V-band

operators are obligated to meet specific deployment targets.

Delays and cancellations. In its 2018 spectrum outlook, Canada's regulator, ISED, planned to auction 28 GHz spectrum in 2021 ahead of C-band spectrum. mmWave was later deprioritized and pushed to a yet to be determined date post the C-band auction which is planned for October 2023.

Canada is not alone in pushing decisions on mmWave further out in time. Reasons for delays includes lukewarm interest by MNOs as well as scheduling delays caused by the Covid pandemic.

Deployments. The earliest markets for mmWave deployment are in the United States, Japan and Korea, where regulators were first to authorize spectrum for mobile access.

As mentioned, Korea required MNOs to deploy 15,000 28 GHz base stations by end of 2021. In an April 2022 audit, deployments were: 1,586, 1,868 and 1,605 by KT, LG U+ and SKT, respectively.

In Japan, NTT Docomo deployed 22,000 mmWave base stations by July 2022. Rakuten Mobile deployed 4,328 by the end of 2021.

In the United States, Verizon leads 28 GHz mmWave deployments base stations with 35,000 sites on air by March 2022. We attribute Verizon's use of mmWave to their market positioning as a premium service provider coupled with the precarious competitive situation of having no mid-band holdings to compete with T-Mobile's 2.5 GHz until Verizon secured C-band spectrum in the 2021 auction.

mmWave at the World Radiocommunication Conference

WRC-15 was a pivotal conference that affirmed the primacy of satellite services in several bands including L, Ku and Ka. The ITU protects the 27.5-31 GHz band for satellite broadband services including earth station in motion (ESIM) following WRC-19. Therefore, WRC-15 decided not to consider these bands for 5G services.

WRC-19 identified 24.25 – 27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 and 66-71 GHz for 5G services.

National administrators, primarily in the US, Japan and Korea, were first to open up the 28 GHz band (3GPP band plan n257/n261) for 5G services. Europe followed closely opting to allocate the 26 GHz (band plan n258) instead.

Allocations for Private Networks. Several regulators decided to make parts of mmWave frequencies available for enterprise private wireless networks, including China, France, Germany, Hong Kong, Japan, and the UK among others.

The market is at a relatively early stage with a focus on testing the technology, particularly in advanced manufacturing that require multiple Gbps throughput rates.

Key Takeaways

- mmWave is in a similar situation today to that of mid-band spectrum (e.g. C-band/3.5 GHz) in the 2000's prior to the advent of massive MIMO technology as implemented in 5GNR: many MNOs are indifferent to mmWave which becomes part of their spectrum inventory.
- Auction results in markets outside the United States validate the disinterest of MNOs as evident by the number of auctions that failed to get the interest of MNOs who largely paid the reserve price.
- Deployments of mmWave in the three main applications – mobile, fixed wireless access and private networks – is still characterized by low volumes which could be detrimental to the business case of vendors. This would be particularly the case in an environment of high cost of capital that pushes out a positive return on investment further into the future.
- We see mmWave being part of future wireless technology evolution – such as 6G and satellite-borne mobile networks – where advances in semiconductors will lead to greater signal processing capabilities, thus contributing to improved cost/benefit tradeoffs.

About Xona Partners

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Industry Update – MWC2023: Velocity or Suspended Animation?

Overview. Mobile World Congress 2023 is back to its old glory as the top telecom/Internet event, with attendees rushing to physically meet post the Covid era. It launched under the "Velocity" theme to highlight the speed at which technology was accelerating. This contrasted against a backdrop of market and financial challenges plaguing the mobile industry ecosystem which were evident in keynotes and in conversations with our colleagues and clients on the exhibition floor. Such economic headwinds, at a time when most operators who have the means to launch 5G already did, leaves the market in a state of suspended animation, which we feel is an appropriate description of the state of the industry today.

Exposing Telco Weakness. It was particularly evident in the financial weakness of European telcos who bitterly complained about their inability to monetize their networks in comparison with the Cloud and application service providers. European telcos also complained about their inability to execute on M&As due to regulatory constraints, and expressed their desire to see the over-the-top providers pay their fair share, an idea that keeps coming back, but typically fails to gain traction. All this notably comes against a backdrop of record subsidies by governments in digital infrastructure initiated in response to pandemic lockdowns from which both operators and equipment vendors benefited.

North American operators are in a better shape despite a pool of debt from a series of spectrum auctions piled on top of aggressive customer acquisition campaigns and competitive environment in the US. But they too are undergoing a transformation. We have already seen major service providers (e.g. Verizon, AT&T) fully or partially unloading assets to pay for debt and improve their financial statements (e.g. Yahoo, Warner Media, DirectTV). Now, AT&T is thought to be seeking to undo its $600m acquisition of cybersecurity firm AlienVault which was completed 5 years ago.

Asian operators who vary in performance have opted to continue searching for new applications and services that will drive revenues. After leading in launching 5G –

General Observations

Over 88,500 participants attended the event according to GSMA. While data on the origin of the participants is not disclosed, the vast majority were European, and a good subset of that being attendees at the 4YFN event, hosted with MWC, and framed as the largest tech-startup event in the world.

A few exhibitors had upgraded their presence with larger booth space than in prior years, including the consulting companies like McKinsey, PwC, E&Y, BCG and others who have performed well during the pandemic in delivering on digital transformation projects. Others who upgraded in size include low-tier equipment vendors such as Airspan, Baicells, and Comba. On the other hand, most of the large vendors limited the attendance of their staff against a background of layoffs and budget cuts. Hyperscalers, and in particular AWS, had a huge presence, underscoring their push to sell their value proposition to telcos.

already 4 years ago by Korean operators – ARPU erosion resumed after an initial uptick. What such monetizable services are is not clear; hence the dilemma of telcos across the globe.

As a consequence, we found telcos are pondering, more than ever before, whether strategies to spin off tower, fiber and data centers are appropriate given the critical importance of some of these assets in securing a differentiated offering and enabling new services.

Vendor Transformation. The weakness of the telco space has long made vendors look for alternative markets. Hence, the Nokia rebrand launched at MWC2023 should not be viewed in isolation. Their new focus on the enterprise will be tested. Ericsson is in a similar situation following a string of acquisitions that provides it with an enterprise element (Cradlepoint, Vonage), but yet to make a dent in the enterprise market.

Samsung on the other hand is quietly benefiting from geopolitical tensions that saw Chinese vendors banned in most Western countries, and more seriously, from being able to acquire the technology necessary to develop their solutions. In a market that can sustain a few vendors, the door is quickly closing on challengers with alternative approaches, such as Rakuten Symphony and Mavenir who lack the deep pockets to go head-to-head against the incumbent vendors. [Samsung won at Dish Networks in part due to "new RAN" vendor missteps.] The strategy of promoting open and virtualized radio access network solutions is yet to pay off in the service provider sector despite promises of Vodafone (30% of European networks by 2030, or 30,000 sites), Telefonica and Orange among others of such deployments.

This year saw the return of Huawei with a number of new products that won it 5 Glomo awards (FDD beamforming, massive MIMO, and rural connectivity solution, private networks, and connected health). Nevertheless, the question is to what extent Huawei will be able to keep its technical lead given that it lost access to advanced semiconductors?

Looking further ahead, the disaggregation of mobile networks has opened the door for new vendors from across the globe, and in particular from Taiwan, Japan and China, to produce core and RAN solutions that will put pressure on vendors based elsewhere who are addressing niche markets.

No Dominant Technology Theme. In contrast to past years, there was no specific theme that dominated the event. However, we do note three main areas that are worthy of a deeper look:

1. **Telecom Cloud Platforms:** The Hyperscalers did a big push positioning their public/hybrid clouds as platforms to run 5G core and progressively RAN networks. AWS, GCP, Azure showcased their ongoing deployment with some early telco adopters, such as Dish Networks, highlighting the business case with a focus on cost reduction for network rollouts. Pretty much all telcos are in observation mode trying to assess their strategies which range from in-house solutions to leveraging various cloud deployment models. In this, the hyperscalers are in competition with various other companies such as VMware and Red Hat who have also been positioning their cloud solutions.
2. **GSMA Open Gateway Initiative:** This is one of the key highlights of MWC2023. A group of 21 operators (AT&T, China Mobile, Deutsche Telekom, KDDI, Orange, Telefonica, Verizon and Vodafone included) signed onto a framework to provide developers access to networks through universal network APIs. 8 APIs were defined in this initial launch with more to follow in the future. Several operators such as Orange, Vodafone and Telefonica demonstrated how these APIs

would be used in a variety of use cases including mobile gaming, interactive high definition video, and number verification and device location.

3. **Satellite-to-Handset (DTH) Communications:** The presence of satellite companies was notable, in addition to devices and services that leverage satellite communications. This segment of the market is awash with innovation of which we note the service from Bullitt which uses a Motorola Defy device to bridge a cellphone to Echostar and Intelsat GEO satellites over NB-IoT link. This GEO-based service could severely undercut nascent LEO-based low-bitrate messaging services due to its simplicity and low cost; it is bound to set the performance bar higher for constellations seeking to provide low-bit rate messaging services. The solution won a Best in Show Glomo award alongside Apple's Emergency SoS via Satellite that won the Disruptive Device Innovation award.

Other areas of observations, include:

- **5G Private Enterprise Networks**: As a potential new source of revenue for operators and vendors, private networks are progressing at an uneven pace across the globe, with a large number of vendors positioning their solutions and working closely with systems integrators on deployments. mmWave technology is now being positioned for private networks which raises questions on potential market size. Moreover, there's awareness that small cells are needed as opposed to the more expensive server-based split-architecture ORAN solutions that had the most attention from the infrastructure equipment ecosystem. This shift in perspective will have a ripple effect through the supply chain including semiconductor and equipment vendors.
- **IoT**: Largely absent! Unlike past years where the show floor was awash of different industrial devices and personal gadgets, IoT is clearly in the plateau of productivity with selective deployment success, building on incremental evolution. Operator IoT revenue remain disappointingly low. NB-IoT success in China is not matched in the rest of the world. Nevertheless, RedCap made its debut at MWC2023 with solutions from Qualcomm (baseband chipset) and Rhode and Schwarz (test equipment), China Unicom (modules) among others.
- **eSIM**: This is a quiet winner; typical of technologies that receive little press and achieve good market traction! eSIMs are potential enablers of private networks, roaming services, and many other applications that directly benefit consumers (perhaps to the detriment of incumbent operators).
- **Quantum security**: SK Telekom displayed a chip that integrates quantum random number generation function and a cryptographic communication function. Other security solutions were also on display from large semiconductor companies like Marvell as well as startups addressing key distribution and data encryption at rest or in motion. The GSMA facilitated a first ever seminar on post-quantum security for telcos. We continue to keep a keen eye on developments in quantum cryptography because of its disruptive potential especially given the on-going global tensions that make communication and data security paramount.
- **6G**: There were a few displays referencing 6G. Some took the approach of presenting 6G from the perspective of applications, such as Nokia's sensing technology which reminds us of what's already integrated into vehicles. Immersive tech and the metaverse were other aspects of this positioning which is what NTT Docomo did with XR use cases. Others linked 6G to technologies, such as point-to-point THz communications by Fraunhofer HHI. 6G [mercifully] was not front-and-center as operators are yet to deploy 'the real 5G' represented by standalone mode core network and many features that make up both 5G and 5G Advanced roadmaps. In

the current environment of shrinking capex, operators are looking to monetize 5G and are in no mood to discuss 6G. This is also matched by vendors who have their own challenges to deal with and are in no rush to promote 6G.

- **AI**: AI was right, left and center, pitched by vendors and service providers alike. Yet, most AI use cases were repackaging of past one which include network optimization, intelligent diagnostics, network automation and other operational and customer facing applications. The Generative AI theme was also very present with chipsets vendors showcasing their performance vs. benchmarks. Qualcomm was the most aggressive in this direction, showing "Stable Diffusion" AI models running on their smartphone chipsets and mapping them to new applications that will over time run on smartphones.

If there was a clear "loser," it would be the Metaverse. There were demos of XR solutions as in prior years, but they are no longer a novelty. The Web3.0 and blockchain applications were also on tap, but probably suffering from the ongoing crypto winter. Other areas such as Edge Computing, Open RAN, Autonomous Robots and others were present, but we feel little has changed since last year to warrant a deeper dive.

Key Takeaways

- The operator ecosystem is bifurcating with North American and some Asian operators leading technology adoption and introducing new services, while European operators are lagging in performance. There will be more pressure for M&As and/or asset spin-offs as new revenue opportunities are slow to materialize.
- There is an abundance of technology but limited ability to monetize it. This adversely impacts vendors large or small making the market ripe for M&As. Technology providers will have to carefully consider their strategies towards developing new sources of revenue.
- Convergence of satellite and terrestrial networks, telecom cloud platforms by hyperscalers and the framework for Open Gateway APIs are the top three noteworthy technology domains.
- Operators banding together to offer Open Gateway APIs to developers is an initiative worth watching, but as in the past, gaining adoption is the key challenge to overcome.
- The efforts of hyperscalers to bring telco network functions into their clouds will definitely be the topic to watch this year, as tradeoffs between economics, resiliency, dependency and manageability will have to be heavily assessed prior to taking critical strategic decisions.

About Xona Partners

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Enabling Direct-to-Handset Satellite Connectivity: Highlights from the Proposed FCC Regulations

Overview. Direct-to-handset satellite services proposed by the likes of Lynk Global, AST SpaceMobile and SpaceX are bold commercial endeavors that lack the appropriate regulatory framework for sharing spectrum between mobile network operators and satellite service providers. The FCC has recently proposed a framework that governs the use of mobile spectrum by satellite operators, which it calls Supplementary Coverage from Space (SCS). Here, we distill the key elements of the FCC's Notice of Proposed Rule Making of March 16, 2023 and project the highlights onto a global scale since low-earth orbit (LEO) constellations are global commercial projects that cannot survive by relying on revenue from a single market/country.

Spectrum for Coverage from Space. The FCC targets sub-3 GHz frequency division duplexed spectrum (part of 5G NR FR1 bands), leaving aside spectrum in 5G NR FR2 bands, primarily millimetre-wave, for future consideration. SCS services would be approved for these bands:

- **600 MHz:** 614-652 MHz and 663-698 MHz;
- **700 MHz:** 698-758 MHz, 775 MHz-788 MHz, and 805-806 MHz; this excludes portions of the 700 MHz bands allocated for public safety (758-775 MHz and 788-805 MHz);
- **800 MHz:** 824-849 MHz and 869-894 MHz;
- **Broadband PCS:** 1850-1915 MHz and 1930-1995 MHz; and
- **WCS:** 2305-2320 MHz and 2345-2360 MHz.

The FCC will authorize mobile-satellite service (space-to-Earth and Earth-to-space) in these bands and will modify the US frequency allocation tables to add SCS as co-primary allocation.

Competing Models for Direct-to-Handset Satellite Connectivity

There are broadly two competing spectrum models for mobile devices to connect with satellites.

The first access model uses spectrum assigned to the terrestrial service provider. We differentiate two sub classes of this access mode: 1. Spectrum slice where the terrestrial service provider dedicates a spectrum band exclusively for satellite services; and 2. Spectrum in-fill where the terrestrial operator uses the same band for both terrestrial and satellite services. In the latter case, it is necessary to have active interference management to protect terrestrial services. Examples of this access technique includes SpaceX and Lynk (spectrum slice) and AST SpaceMobile (spectrum in-fill)

The second access mode uses spectrum designated for satellites. We call this model over-the-top, since it is not dependent on the terrestrial service provider spectrum. This access mode requires phones that support additional spectrum bands and waveforms. As a result, phones supporting this mode will be a little more expensive. Examples of this service includes Globalstar for Apple iPhones and Iridium which is collaborating with Qualcomm for the Android ecosystem.

The FCC framework addresses the first access mode where satellites are using terrestrial spectrum.

All these bands are available for flexible use, i.e. the FCC does not prescribe the specific application or use case.

For all bands, except the 800 MHz band, the proposal is relatively straight forward. The 800 MHz "Cellular Band," was the first band to be allocated to mobile communications in the 1980s. It has legacy licensing rules that might complicate the provision of SCS: a licensed area is the composite of service areas where service can be provided (known as Cellular Geographic Service Area - CGSA). An unserved area beyond the 800 MHz cellular licensee's coverage remains unlicensed in the FCC's spectrum inventory. This is exactly where satellite services are needed. Under the proposed rules, the Cellular Band licensee is required to expand the CGSA to include adjacent unserved areas.

Addressable Coverage Area: To eliminate the potential for interference between satellite and terrestrial mobile networks, the FCC will require the terrestrial spectrum licensee to hold all co-channel licenses in a Geographically Independent Area (GIA). Six areas are defined: The continental US, Alaska, Hawaii, American Samoa, Puerto Rico & Virgin Islands, and Guam.

Note that these areas are geographically independent with significant separation between them. The terrestrial service provider will need to have a spectrum license over an entire GIA to enable SCS services. For example, T-Mobile will allocate a slice of its PCS band spectrum to SpaceX for service over the continental US. Further collaboration or steps are required to limit interference with terrestrial networks in Canada and Mexico.

The continental US is a large area which makes it easier to design satellite antenna systems that prevent spillover satellite coverage into co-channel frequency bands allocated to geographically adjacent licensees. This is not the case for many parts of world where national boundaries lead to

Overview of Direct-to-Satellite Market Activities

A number of companies are vying for part of the DTH market. The ones that will use MNO spectrum include:

- Lynk Global has launched three satellites and received FCC authorization to deploy 10 satellites. It has announced multiple service provider agreements claiming 25. Lynk's initial service will focus on SMS services.
- AST SpaceMobile plans a 243 satellite constellation. It launched its latest test satellite in November 2022. Code-named Bluewalker 3, it features a 64.4 m^2 antenna. AST is collaborating with AT&T, Vodafone and Rakuten among other operators.
- SpaceX announced that it will provide DTH services over T-Mobile PCS G spectrum in August 2022. This will be over some of Starlink Gen 2 satellites.

Two other competing services use "over-the-top" spectrum; i.e. spectrum that the MNOs do not control.

- Globalstar uses its X and L-band spectrum to enable Apple iPhone Emergency SoS service. Globalstar uses its existing bent-pipe satellite architecture.
- Iridium uses its L-band spectrum to enable the Android phone ecosystem offer competing feature to Apple's emergency SoS.

There are two noteworthy aspects to mention:

1. Lacuna Space is an example of a company using 900 MHz unlicensed band spectrum to provide IoT connectivity from satellites (LoRaWAN protocol in this case).
2. Bullitt developed a service that uses a Motorola Defy dongle to connect with phones over Bluetooth and with GEO satellite over NB-IoT connectivity.

small coverage areas that consequently raise the complexity of satellite antennas to prevent co-channel interference. In such markets, collaboration between multiple national regulators would be necessary. This could complicate market access for the satellite service providers.

Devices. Devices play an important role in defining the service and potential business opportunity. For this initial set of regulations, the FCC does not authorize a satellite service to satellite-only devices using terrestrial spectrum. The mobile network operator is required to acquire a blanket earth station license for its subscribers' terrestrial devices that will use the SCS service. This includes handset and IoT devices, but excludes user terminals used for fixed wireless access such as the ones for SpaceX Starlink and AWS Kuiper. This of course limits, for the time being, the addressable market for the direct-to-handset satellite constellations. [As a side note, SpaceX started providing consumer fixed wireless access connectivity, and later entered into enterprise FWA services to be followed by mobile satellite services as in connectivity to planes and ships.]

Emergency Services/911 Calling. Mobile network operators are required to support basic and Enhanced 911 (E911), outdoor and indoor location accuracy, and text-to-911. On the other hand, mobile satellite services are exempt from supporting emergency/911 calling; but are required to provide emergency call center service. Emergency services are a critical element of the DTH satellite service model as evident in Apple positioning of the recently introduced iPhone 14 Emergency SoS service. Regulations for emergency services/911 calling are pending the consequent deliberations. Wireless Emergency Alerts is a similar feature that is also pending.

Spectrum Lease Arrangement. The satellite operator is required to lease the spectrum from the MNO (under part 1 of FCC rules). This enables the satellite operator to provide SCS service with authorization under part 25 of FCC rules. The question centers on who has effective control of the spectrum license: the satellite operator or the MNO? In answering this question, there are two main models: 1. The licensee retains both de facto and de jure control; and 2. The licensee retains de jure control while de facto control lies with the lessee (the satellite operator). The former is referred to as spectrum manager lease arrangement and does not generally require prior FCC approval, but the licensee (lessor) must notify the FCC ahead of commencing operations. The latter is called de facto spectrum lease arrangement which requires FCC approval prior to the spectrum leasing agreement takes effect.

Since DTH service is new and was not envisioned when the rules for spectrum leasing were defined, it raises certain questions on the lease arrangement, for instance: how to harmonize the term of the lease with the term of the license, and who is ultimately responsible for meeting interference requirements. Many other questions branch out of the lease arrangement that will have to be answered.

Key Takeaways

- The FCC Supplementary Coverage from Space is the first framework for regulating direct-to-handset satellite services allowing satellite operators to communicate with mobile devices over MNO spectrum.
- The current focus is on sub 3 GHz mobile spectrum, which excludes millimeter wave spectrum. The MNO has to own the all co-channel licenses over a Geographically Independent area, of which there are 6 with the continental US being the most prominent.
- The size and location of the service areas impacts the design and complexity of the satellite antennas and impacts the financial viability of the venture as well since DTH satellite constellations need to have a global revenue stream for commercial profitability.
- The SCS framework excludes satellite-only devices; in other words, it is a service for cellular mobility and IoT, but not for fixed wireless access.
- Satellite operator will have to lease the spectrum from the MNO and operate under FCC part 25 rules. The full lease arrangements as well as many important questions, such as interference management and emergency calling, are yet to be defined.

Telecom Cloud Platforms: A White Knight or Trojan Horse?

Overview. The extension of the public cloud to telecom networks is one of the most important technology trends with far reaching consequences for both cloud providers (CPs) and telcos. CPs are making an aggressive bid for telcos to host their network infrastructure on the public cloud. They argue that this will help telcos cut their costs, evolve their service offering and satisfy the requirements of their investors and shareholders, pitching it as a win-win for telcos and CPs. The pitch should not be simply viewed as such, but rather one must look at it from the perspective of integrating public clouds with telecom networks, which comes with a variety of fundamental trade-offs to assess. In the process, the telco network would be subsumed by the cloud where the CP stack operates at different locations along the core-edge-access continuum, and the telecom network provides the connectivity plumbing between the disparate parts. This end-vision will take many years to play out – if it does at all. For the time-being, telecom executives face a myriad of complex options and decisions on how to evolve their networks, while facing stringent cost optimization constraints and deadlines to execute on these decisions.

The telco cloud dilemma. Telcos realized since the early 2010's that increasing network complexity and lack of flexibility required a new paradigm to implement and deploy networks. They watched the success of cloud providers with envy, and they attempted but failed at becoming public cloud providers themselves.

For over a decade, telcos have been on an arduous journey to virtualize their operation and business support systems (OSS/BSS), core network, and more recently the radio access network. Most of the execution was completed in-house by leveraging their own private clouds, or that of their networking vendors.

Developing telco cloud infrastructure is complex and expensive, with no clear standards to follow, as only the largest service providers could lead. Yet, these endeavors have not met service provider expectations. Success is mixed: the complexity of telecom functions coupled with execution failures left for much to be desired. In the meantime, cloud providers made leaps in technological innovations, building on their hyperscale workload deployment drivers. Kubernetes for containerization, deployed, orchestrated and managed at scale is but one example.

Telco clouds, which are largely based on open source projects such as OpenStack or other, private/public cloud solutions such as VMWare or IBM/Red Hat, are trying hard to match the performance, cost metrics and capabilities of the public clouds. The services, operations and automation tools that cloud players developed to manage the operation of their clouds and the applications that run on them could not be matched by telcos. This is in part a question of investment and collaboration within the telecom industry. The fragmentation of telcos and aversion to collaboration are among the reasons, as are the scale of the undertaking, expertise it requires, and the cost structure for managing large clouds which benefit from economies of scale that are friendlier to cloud providers.

Telco fragmentation happens along different dimensions, for instance, the size and number of telcos, and the number of approaches possible to implement, deploy and manage clouds. To this we add a large number of different systems that comprise the telco network. For example, AT&T's mobile core network includes more than 60 cloud-native network element functions and virtual network functions from over 15 different vendors, all requiring various underlying software and hardware infrastructures. The mix of core and radio vendors, themselves pushing their virtualization and cloud strategies, adds to the interoperability, cost and deployment complexity. All this could make a case for vertical integration of which Rakuten is a prime, albeit perhaps an extreme, example: it went aggressive in building its own telecom cloud platform making several acquisitions in the process (e.g. $1 B for Altiostar RAN; Robin.io for Kubernetes platform; and Innoeye for cloud service deployment). Rakuten took its solutions to other operators, but is yet to make a significant breakthrough.

Cloud players telco strategies. Public cloud providers who share the challenge of extending the reach of their clouds see a great opportunity in telecom public networks and enterprise 4G/5G private wireless networks. The ultimate goal, even if not always directly stated, is to host the telecom network infrastructure, from radio to core to operating and business support systems. For this, they have taken different approaches to enter the telco market leveraging common interests including a legacy of partnership for public cloud services, and most recently as edge cloud partners.

Azure made two acquisitions valued at over $1.6 B in core network elements (Affirmed EPC, Metaswitch IMS) and will run portions of the AT&T's core network (OSS/BSS, mobile core) on Azure stack at AT&T premises, while progressively developing its offering to host telco network infrastructure or leverage its

The Case for Migrating to the Public Cloud: How Telecom Workloads are Different from IT Workloads

Economics drive the migration to the public cloud. This remains primarily true for well-chosen IT workloads even as reverse migration to private clouds is important today, ironically for cost optimization. But the economics are not as obvious for telecom infrastructure workloads.

Telecom networks are spread over large geographies where workloads run in specifically designed data canters, central offices, and edge locations such as cell sites, to optimize for performance, redundancy and cost. This comes with inherent characteristics for many telco workloads that are different from common IT and enterprise workloads running on public clouds.

While many telco workloads have similar requirements to IT ones, many others have unique requirements for throughput, latency, jitter, resiliency and real-time compute environment. Data-plane functions are an example (e.g. air-interface physical layer). Consequently, such telco workloads demand a high level of control, fault tolerance, recovery and availability. These requirements factor into the choice of both hardware and software leading to specific design and architectural choices that govern telco networks.

Telcos managed to first virtualize non-real-time functions with low demand for compute power, such as operation and business support system functions, and parts of the mobile core network. On the other hand, the radio access network (RAN) functions are among the most complex to virtualize because of their stringent performance requirements. Such functions require tight coupling between the application function and the underlying hardware and software stack leading to vendor lock. Incidentally, the RAN functions also represent the largest revenue opportunity for the CPs. This partially explains their foray into virtual RAN and enterprise private networks. But to capitalize, CPs need to customize certain aspects of their clouds to accommodate telco requirements.

acquisitions to provide some of that infrastructure directly.

AWS is leveraging its edge products (Wavelength edge cloud offering) as an entry point, and aggressively pitching itself as the prime cloud infrastructure to host the core and radio networks. A clear example of that is its tie-up with Dish Networks to run its core and control functions of radio access on AWS stack (thus, AWS has the deepest reach into the telecom infrastructure hosting).

Google, which has the smallest market share of the three major public cloud providers, positions its analytics and data mining solutions with network operators (e.g. Vodafone, Bell and Telenet). The aim is to evolve into a provider of infrastructure hosting services for select elements of the core and radio telecom network.

Enterprise private wireless networks is an adjacent market entry strategy that all three major cloud providers are in process of leveraging. This is an interesting approach in telco-cloud provider tie-up since it represents an opportunity for collaboration and partnership in the short term, yet it puts telco players and cloud providers in direct competition in the long term, as we see with AWS private enterprise network offering, which is in direct competition with telcos.

Telco's migration options. Telcos face difficult decisions on how to evolve their networks. The options in summary:

1. *Migrate to public cloud*: Telcos need to decide what functions to run on public clouds (OSS/BSS, core network and potentially RAN); and how to phase out such migration.

   Telcos also need to decide on how and where these functions will run once they are on public cloud infrastructure (data center infrastructure, hosting models, infrastructure management and security). For example, AT&T will run its network functions over Azure stack on premise instead of Azure data centers. It is also possible to use more than one cloud provider for resiliency and redundancy.
2. *Maintain status quo* with existing private/hybrid/public clouds and virtualization platforms which typically include IBM/Red Hat or VMWare-based platforms and, in some cases, the clouds offered directly by networking infrastructure vendors such as Nokia, Huawei and Ericsson. Verizon and T-Mobile are in this camp for a part of their network functions.
3. *Choose a hybrid approach* in which case there are myriads of options available. This approach includes different variants of public-private hybrid cloud implementations, mixing private clouds with public clouds. As an example, it could mean migrating certain workloads to public clouds (e.g. OSS/BSS) while retaining ownership of other workloads on private clouds (e.g. mobile core network).

Telco decision criteria. In deciding on the most suitable implementation, telcos need to consider the approach that solves their problem, which are different for different telcos. Hence, while no one size fits all, some issues to consider include:

- *Inter-cloud migration and vendor lock*: It is very challenging to move applications between clouds and to switch between cloud providers after building network functions on a certain cloud infrastructure. [So much so that UK regulator Ofcom is proposing the Competition and Markets Authority investigate the cloud players.] Telcos that complain about vendor-lock in the radio access network will experience an even greater tie-up as the entire infrastructure software and hardware layer will be controlled by a single entity. This is concerning enough for European operators to launch Sylva, the first open source initiative under Linux Foundation Europe, to study migration between clouds.

A related aspect is global geopolitics and how countries and their respective telcos view the reliance on a few US technology companies. [Chinese cloud providers like Tencent and Alibaba have not yet made a similar move; only Huawei is pursuing this path with telcos.]

- *Data privacy and compliance*: Telcos have requirements to meet for data localization and privacy that vary among countries. This places requirements on where the infrastructure is hosted and how data flows and is stored.
- *Cybersecurity*: This includes a number of issues such as hardening different layers of the stack; process or function isolation, decreasing the attack surface, managing access and identity and encrypting internal and external communications. Telcos will have to decide on what cybersecurity functions they are confortable leaving in the hands of the cloud providers.
- *Performance and resiliency*: Performance covers a wide range of issues related to the workloads that will run on the cloud infrastructure. It covers control-plane functions which typically have high transaction rate, but low data throughput; and data-plane functions which have high throughput and may have real-time requirements [base stations and deep-packet inspection systems are examples of systems difficult to run on cloud infrastructure].
  Performance also addresses the availability of the network and redundancy needed to maintain an acceptable level of availability. Major outages, as seen on the Dish network, would have telcos think carefully on how to address network availability requirements once they depend on cloud providers for the network infrastructure. Service level agreements (SLAs) and meeting the appropriate key performance indicators (KPIs) become important issues for telcos to assess as they consider migrating critical functions to the public cloud.
- *Cost*: Microsoft Azure claims public cloud costs 40% less than operators' current cloud approach. UK operator Three claims that Azure could reduce its IT expenses by one third. Yet, assessing cost savings from using public clouds is not trivial since it is impossible to assess the long-term relationship in the marriage between telcos and cloud-providers. For instance, synchronizing technology roadmaps requires high commitment that's backed by good perceived benefits which predicates high return on investment. For this reason, some service providers, like Deutsche Telekom discount the costs and would rather focus on the benefits (for them, it is data analytics and new revenue generating services). Moreover, enterprises are looking more carefully at cost trade-offs between public and private clouds, which is giving telcos another dimension to assess.

Different clouds – AWS, Azure, Google or others – offer different features and capabilities, so they each need to be assessed on its own merit. For instance, each of these clouds has its own implementation of security that needs to be assessed for the respective telecom service provider.

Ecosystem impact. Should cloud players be successful in penetrating the telco sector, they have a path to further distribute their clouds at favorable economics, and hosting an increasing number of telcos over such public clouds. The economic value increases with deeper penetration towards the edge of the network, either hosting edge workloads or network elements functions (radio, core). However, this is where it becomes more challenging: the further out from the core, the harder it is technically to deploy network functions on cloud infrastructure as more customization will be required, and the more challenging the economics become.

Cloud players will have to build up teams of networking experts, processes and organizational structures, at scale to manage such infrastructure. They will have to ensure that the corresponding economics match the high margins they are accustomed to in the overall public cloud services market.

As for telcos, they are at cross-roads: they need to carefully weigh the pros and cons of a tie-up with a cloud provider as we detailed in this note. At its best, telcos may find the public cloud the appropriate platform to be agile and efficient in operating their networks. At its worst, telcos would lose control of their destiny and possibility for differentiation to become true dumb pipes. In this, there is no universal option that fits all telcos, so each would need to consider their unique status in the context of market dynamics, technology prowess, regulatory and policy among other factors.

Another impact would be on that of network function vendors. Telco migration to public cloud requires collaboration between both camps. For network functions that require tight coupling between software and hardware, this means a new experience for both parties. It also means lower revenues for vendors who typically bundle hardware and software.

Telco migration to public cloud raises a new set of dynamics for the interaction between these three principal parties unlike anything before. Process, business models and many other aspects will need to adapt to this new model. All this is occurring at a critical time when telcos are under pressure to cut costs and increase margins; a fact not lost on the cloud providers who are bringing this argument forward to entice the telcos to move to their clouds.

Key Takeaways

- Telco-Cloud providers tie-up facilitates the latter to access the network edge for proximity to end-users: there lies the highest financial reward, but also the highest technical challenge due to customization.
- Telcos face a myriad of options on how to use public clouds. Migration to the public cloud is only one among many that include different hybrid private-public architectures to evaluate.
- Evaluation criteria needs to include Inter-cloud migration, vendor lock-in, data privacy and compliance, cybersecurity, performance and resiliency – all of which are critical factors to be accounted for aside from cost.
- The challenge lies in assessing long-term juxtaposition of telcos and cloud providers which is one reason for the difficult decision set facing telcos today.

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About Xona Partners

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