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Telecom & Cloud Infrastructure Technology and Investment Trends

A look ahead into 2023

January 10, 2023

Preface

We have compiled an assortment of Insight Notes we published during the course of 2022. These Notes are representative of some of the areas where our team has been involved in providing expert technical and commercial due diligence to financial investors, corporations and government organizations seeking to evaluate new business opportunities in telecom, data and cloud infrastructure sectors. The sectors we have particularly focused on during 2022 include:

Direct-to-handset (DTH) Low Earth Orbit (LEO) satellite communications. DTH saw a flurry of activities that attracted the attention of the industry. SpaceX and T-Mobile announced their DTH partnership a few short weeks ahead of Apple releasing the iPhone 14 with text messaging services over Globalstar satellites. We attached here the Insight Notes covering both initiatives as well as that of AST SpaceMobile. In the field of NGSOs, our team has been busy providing both technology and commercial advisory services related to product definition, business case development and go-to-market strategy.

Fiber and fixed wireless access. Government subsidies flowed into rural and remote area development to help bridge the digital divide. Fiber networks received the bulk of this investment. Fixed wireless access (FWA) also benefited. We helped companies planning fiber and FWA deployments expedite the technology selection, design and planning processes with our financial and technology modeling tools. Here, we included two papers on this topic: one focusing on comparing fiber to FWA, while the second discusses automation tools in the network planning process.

Enterprise private wireless networks. Private networks based on cellular 4G & 5G technologies have been illusive over the years. To help enterprises make educated decisions, we provided custom workshops on to help organizations draft their market and technology strategy, and lead the commercial deployment of some of the first pure 5G enterprise networks. Some of the key aspects in this area include the competitive assessment of technologies such as Wi-Fi (see the respective note on this), integration into cloud connectivity models and cybersecurity architectures.

Energy consumption in data centers and telecom networks. Energy emerged as a major topic in 2022 for geopolitical and environmental reasons. The impact was most felt in the data center sector, especially in Europe, but in other markets as well. We presented a view on power consumption in telecom networks which is an area fraught with inaccurate information.

5G Evolution. Edge computing and cloud-native architecture are cornerstone topics in the evolution of wireless networks. In this supplement, we provided an overview of how operators view Open RAN and their attitude towards new business models in the telecom supply chain.

These topics will remain at the core of the foreseen developments in 2023. The difference is 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.

In This Edition

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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T-Mobile + SpaceX Direct Satellite-to-Handset Service: Lots of Hype and Little Reality

Overview. T-Mobile and Space-X announced a partnership to provide direct satellite-to-handset service using T-Mobile PCS frequency band. While this is new to Space-X, there are other players in the industry working on the same objective, primarily AST SpaceMobile and Lynk. Apple is rumored to launch this type of service with Globalstar.

The service will enable users outside T-Mobile's terrestrial network coverage to connect to a Starlink satellite (Gen 2) to send and receive text messages and voice calls (future phase).

Service Highlights

- Service will use T-Mobile's nationwide PCS band (1900 MHz)
- Service includes text messaging in first phase, followed by voice later
- Supports 2-4 Mbps per satellite
- SpaceX Generation 2 satellites will provide the service
- Phased array antenna will be designed measuring ~5 m a side for a total area of ~25 m^2

Key Takeaways

- The service requires operators to assign part of their spectrum exclusively for satellite communication which may prove challenging for some
- The service is for low-bit rate of a few kbps for emergency use through text messages and voice calling; it is not capable of scaling to higher throughput
- Starlink Gen2 satellites will need to undergo significant redesign to include cellular technology. There will be significant impact on the overall SpaceX business case.

The Technical Background. We develop this technical analysis to help answer critical questions about the service and its implications. The analysis focuses on the uplink path from the mobile handset to the satellite. This is because the uplink is typically the weaker link in LTE and 5G systems.

Mobile handsets transmit at 0.2 W (23 dBm) and feature a low gain antenna (typically 0 dBi). This makes for an effective transmitted power (EiRP) of 23 dBm.

The receiving satellite is orbiting the earth at around 550 km. Using the Friis transmission equation we calculate the free space path loss to be 153 dB for 1900 MHz frequency (PCS band).

The mobile handset power that the satellite sees is then -130 dBm (23 - 153).

To decode an LTE signal at the lowest modulation (QPSK), the signal power needs to exceed -105 dBm. This value factors several assumptions such as a user throughput of 32 kbps in a 5 MHz channel, and a single receive antenna. In practice, the receiver sensitivity is a matter of vendor implementation.

We would also add some margins to account for potential fading and lack of polarization alignment between the transmit and receive antennas. Let's say this is about 4dB. This brings the signal level at the receiver to -101 dBm.

As a result, the satellite antenna gain needs to be -101 - (-130) = 29 dBi.

We can now calculate the effective aperture of the antenna which gives an idea about its size. This comes to about 1.4 m^2. The form factor of the antenna could take on different shapes, but its aperture, or area needs to be 1.4 m^2. For comparison, base station antennas in this band are typically 17 dBi and 1.5 m tall (estimated aperture for such antennas is in the neighbourhood of 0.1 m^2).

Next, I estimate the antenna half-power beamwidth to get an idea of the potential coverage area. This is where things get very interesting. For a 29 dBi-gain antenna, assuming perfect efficiency, the half-power beamwidth is about 7.6 degrees. This results in a cell radius of about 36 km and coverage area of about 4,100 sq. km.

The relatively small coverage area has advantages and disadvantages. On the positive side, it allows targeting the antenna to serve specific locations which prevents interference to areas covered by the terrestrial network.

On the negative side, one needs many such antennas to cover a wide area. A satellite could carry multiple antennas. But this is not sufficient to provide permanent coverage over time. This is where some innovation is needed whereby the network could multiplex different areas maximize the utilization of the satellite network while maximizing the coverage spatially and over time.

The analysis above gives a feel for the trade-offs and establishes a framework to think about the commercial implications. It is not meant to be exact since different possibilities exist.

Service Assessment. We can draw a number of observations about the service performance to assess its commercial impact.

- **Limited coverage area.** The satellite needs to support a high gain antenna to close the link budget. This in turn leads to high antenna directivity and small coverage area. As a result, covering large areas requires many antennas and satellites (which is what Elon Musk said at launch). Scalability involves a trade-off between coverage and cost of the LEO network. How to solve this problem will differentiate this type of satellite networks. One hint is that the service, at least initially, will be non-real time as it needs to multiplex different areas. In all, whether this system really eliminates dead-zones is to be proven.
- **Low-bit rate service.** In my calculations, I used a relatively small channel bandwidth of 5 MHz with a user bit rate of 32 kbps. This bit rate is sufficient for low data transmissions including text messaging and voice (codecs run at 9.8 kbps and lower). A smaller channel bandwidth and/or lower bit rate reduces the antenna gain and size requirement, and results in a larger service area. Similarly, a wider channel, such as 20 MHz will increase the antenna size requirements and results in smaller coverage area. Taken all together, direct satellite-to-handset is not a broadband service – and could not be one.
- **Low capacity network.** Elon Musk expected a cell to support between 2-4 mbps. This is about 1250-2500 users per satellite if we assume 32 kbps/user and oversubscription factor of 20. Not a bad number, but we need to think of this in context of the overall market, user behavior and network capability.
- **Spectrum separation and loss.** Satellites will be assigned their own slice of terrestrial spectrum. The alternative option of using the same frequency band on both satellites and terrestrial network requires complex coordination and would still result in interference zones at the edge of coverage footprint. This raises the question on whether operators would perceive sufficient value to dedicate a slice of spectrum for this service.

These observations apply to all companies pursuing direct satellite-to-handset service. They are all governed by the same laws of physics.

Commercial Implications

Direct satellite-to-handset service from T-Mobile and SpaceX is a low-bitrate service for messaging and voice calling. It is not a solution for browsing the web or watching YouTube!

It follows that one can ask the following questions:

1. The service is best described as that for emergencies in areas where terrestrial networks do not exist. Will the business case work out for SpaceX? The Starlink generation 2 satellite will require redesign to support this service. This calls into question matters related to deployment timelines and launch arrangements.
2. Will other operators join the project considering they need to set aside a [small] part of their frequency spectrum? Global scale is necessary for economies of scale and revenue generation.
3. The service will impact a relatively small percentage of users – those who venture outside the terrestrial coverage footprint. Nevertheless, it’s a marketing coup for T-Mobile. In this respect, will T-Mobile succeed in getting subscribers from AT&T and Verizon to compensate for the net cash outflow for including this service into popular plans? And, what will AT&T and Verizon do in response?
4. Will such a service attract government, military and public safety users? And, to what extent could it compete with or be complementary to services of similar capabilities over LEO and GEO satellites?

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Apple-Globalstar: Just an SOS or Birth of the "Global" Telco?

Overview. Apple launched the iPhone 14 Emergency SOS via satellite service allowing a user to send and receive text messages over Globalstar satellites. The direct satellite-to-handset service operates at very low bit rate; it could take 15 seconds to send a message to a satellite with a clear view of the sky, or several minutes under foliage. The message is either sent to emergency centers that accept text or is received at a center staffed by Apple personnel who could call the appropriate emergency line on behalf of the user.

The iPhone 14 includes support for Globalstar S-band spectrum designated by 3GPP under band 53 and 53n for LTE and 5G NR, respectively. Qualcomm supports this band in their Snapdragon X65 ASIC and will include it in future chipsets.

Apple Globalstar Partnership. The Emergency SOS service culminates two and a half years of planning and R&D since the two companies formed a partnership in February 2020.

Apple funded Globalstar with over $110 million in R&D services to date. Apple also will fund 95% of capex in addition to other expenses incurred by Globalstar to launch new satellites. In February 2022, Globalstar and MDA entered into a $327 million contract to launch 17 new satellites by the end of 2025. Globalstar will add 10 ground stations. Many more will be required to scale the service globally which will add to capex.

Key Takeaways

- The Emergency SOS service is an interim low-bit rate, low capacity service for bi-directional text messaging. We expect a significant improvement post 2025 when Globalstar launches new satellites into orbit. The new satellites will be better able to integrate with mobile handsets.
- Apple will incur costs in excess of $400 million related to the satellite segment alone. Scaling the service globally beyond the US and Canada requires further capex for ground stations. The question will be how will Apple monetized the service to reach profitability; or leverage it to enter adjacent markets.
- The service runs in Globalstar’s existing spectrum which is independent of the mobile network operators (MNOs) and behaves as a service overlay. As a result, Apple and Globalstar are not subject to tie-ups and approval by MNOs.
- Globalstar S-band spectrum is licensed for terrestrial use in private wireless networks which could benefit, in addition to enterprises, cable operators and other types of service providers in competition with MNOs. This represent a new revenue potential for Globalstar and potentially for Apple.

Globalstar will allocate 85% of its current and future network capacity to Apple, and will prioritize Apple traffic on its network. The remaining 15% capacity will be allocated by Globalstar to its customers. Globalstar believes this remaining capacity is sufficient to run their existing data, messaging and IoT services, and to continue to grow by up to 50x.

To free capacity, Globalstar will abandon their 2nd generation duplex assets, which provide voice services, taking a $175 million right-off. Voice service revenue has been in decline accounting for 25% of Globalstar's service revenue in 2021 ($31.2 m), about 8% lower than 2020. Globalstar had just over 45.7k duplex customer in 2021, with a 21% decline from 2020.

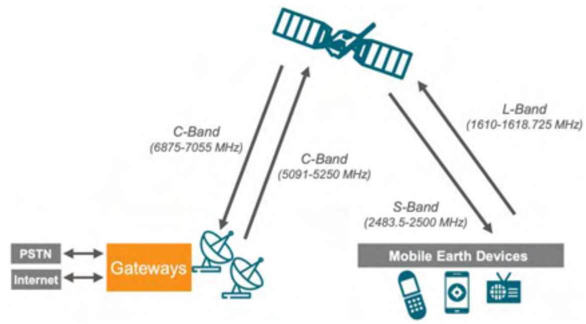
The Emergency SOS service provides similar services to Globalstar's current text messaging and data services (SPOT) with revenue of $46 million in 2021.

Globalstar will transfer its spectrum into a wholly owned subsidiary and issue Apple preferred shares with consent rights prior to actions by Globalstar that may affect the satellite service.

Satellite Network Description. The service runs over 24 Globalstar Gen-2 satellites which were launched between 2010 and 2013. The 15-year life expectancy puts a 2025-2028 timeframe for decommissioning. This is when the new satellites from MDA will be expected to take over.

Globalstar services operate a user downlink in the S-band between 2083.5 - 2495 MHz. The upper frequency limit extends to 2500 MHz for international markets. The user uplink is in the L-band between 1610 - 1618.725 MHz. Globalstar ground stations operate in the C-band.

Globalstar satellites are relays for terrestrial traffic (i.e. bent-pipe). The ground stations host the baseband units which run WCDMA technology for Globalstar's current services.



Gobalstar network architecture. [Source: Globalstar]

Technology Roadmap and Capacity. The Globalstar architecture and technology raises interesting questions on the design choices made by Globalstar and Apple to support the Emergency SOS service. Technically, there are several constraints such as:

1. Low transmit power on mobile devices.
2. Satellites designed as relays for WCDMA.
3. Band 53 supported in the iPhone is time-domain duplex (TDD).

To support this service, the following two approaches could have been taken, including hybrid implementation that combines elements of both:

1. The phone would include a WCDMA modem to interoperate with the Globalstar constellation; and/or
2. The ground stations and satellites would support LTE which is built into the iPhone.

Media reports that the service runs on Band 53 spectrum. This is only be partially true – for the user downlink – because it otherwise raises questions on regulatory and network capacity. The S-Band is licensed for downlink user traffic.

Moreover, the TDD mode could not be used in satellite services because the long path distance results in large loss of capacity. [See Technical Corner for further detail.]

The iPhone 14 transmits in the L-Band to communicate with Globalstar satellites. We suggest it uses the existing uplink technology supported by Globalstar (200 kHz bandwidth). The user downlink is likely LTE (5 MHz bandwidth) provided it is feasible to upgrade the ground stations and make relevant modification to the satellite software to relay LTE signals.

The companies have not released information on their technical approach. Globalstar said it will reveal additional information in November 2022. We flag this technical detail because it affects network capacity and potential capability of the system to provide additional services. It also helps explain why Globalstar needs to reserves 85% of capacity to Apple, in addition to forming a spectrum holding subsidiary with consent rights to Apple.

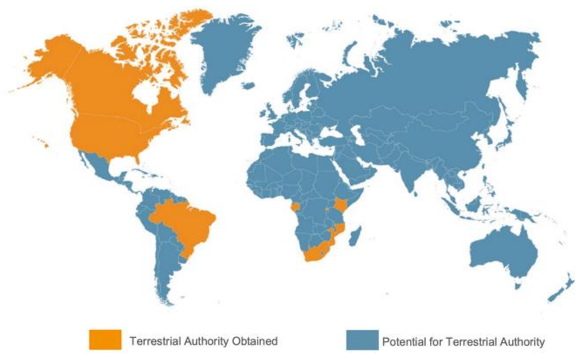
Technical Corner
Globalstar satellites orbit at 1,414 km altitude. A round trip between satellite and earth takes 9.4 msec. Since these satellites are relays and the baseband units are on earth, the round-trip delay is twice that at 18.9 msec, ignoring any latency in the satellite itself for signal processing including converting between the user link and ground station frequencies. An LTE frame is 10 msec long. To avoid interference between downlink and uplink signals, the transmit-receive gap is typically set to the round-trip delay plus the processing margin. This is about twice the frame size, or a loss of two thirds of the channel capacity! For comparison, TD-LTE in terrestrial systems requires a transmit-receive gap under 100 micro seconds, and the switching between the transmit and receive modes occur within the 10 msec frame. Clearly, the choice of TD-LTE leads to much loss in channel capacity due to the large signal travel distance.

Enterprise Private Networks and eSIMs. In 2016, the FCC issued a report and order that allows Globalstar to use 11.5 MHz of its spectrum between 2083.5 and 2495 MHz for terrestrial networks. This forms the core of the strategy that enables enterprise private networks in TD-LTE or 5G.

Globalstar spectrum is harmonized internationally. Today, their terrestrial spectrum is approved in 10 countries totaling 750 million PoPs. This includes the US, Canada, Brazil, South Africa, Kenya and other African countries.

The iPhone 14 will do away with the physical SIM, featuring eSIM only for the US market. This step will remove a major challenge in the operation of private enterprise networks. Older iPhones featuring dual SIM with one being eSIM also provide similar benefit. The eSIM allows mobility across different types of networks and in ensuring good user experience especially at the boundaries of networks. This removes a large obstacle to the adoption of such networks.

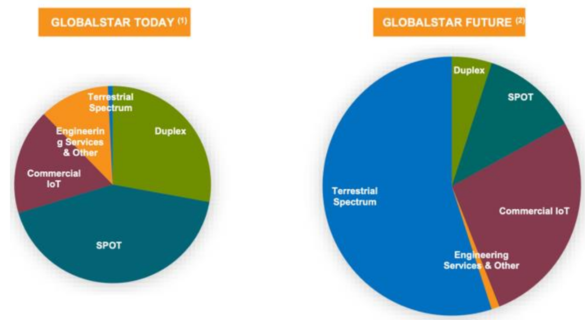
Thus, while much attention focuses on the Emergency SOS via satellite service, taking a broader view to include potential developments for enterprise private networks is important.



Globalstar terrestrial spectrum. [Source: Gobalstar]

Terrestrial Opportunity & Threat. Globalstar had announced earlier that it expects to increase revenue from terrestrial networks to account for over half if its revenues. This makes the partnership between Apple and Globalstar highly strategic. It opens many possibilities for both companies to deliver services using cellular technologies over cellular spectrum in a manner that's completely independent of the mobile network operators.

Through Globalstar, Apple could effectively offer its own mobility services, including IoT, independent of the MNOs. Such services will be limited in throughput and capacity. However, the combination of enterprise private networks, eSIM enabled devices, and satellite communication opens new business opportunities.



Globalstar current and future revenue mix. [Source: Globalstar]

The beneficiaries of such opportunities would include other ecosystem players, such as cable operators, regional and small network operators, system integrators and many others. Mobile network operators could stand to lose the most, which in part helps to explain why T-Mobile chose to partner with SpaceX.

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Optimizing Rural Broadband Techno-Economic Trade-offs

Overview. The COVID pandemic highlighted the “digital divide” between urban and rural areas. Federal and state governments have allocated millions of dollars via programs like RDOF and the infrastructure bill to improve broadband availability in rural and underserved areas across the United States. Other governments took similar action. This brings new opportunities for telecom operators. However, to take advantage of these opportunities, operators must perform a careful financial and operational analysis of each opportunity for the technology and the deployment roadmap. The problem is that such analysis is very tedious and time-consuming. How to make such an analysis in minutes and evaluate technologies such as Fiber To The Home (FTTH) or Fixed Wireless Access (FWA) technology deployment in a market? Here, we highlight our process to help operators quickly plan and develop their access technology roadmap, and make the appropriate technology strategy decisions through an automated design process. While we focus on FTTH and FWA, other broadband access technologies follow similar principals.

Planning through automation. We share our approach [see adjacent box] illustrated by an example where the operator evaluates FTTH and FWA technologies. Here, we plan a greenfield network in Graham County which is tucked away in the beautiful mountainous west of North Carolina. It is a sparsely populated rural county with limited access to broadband infrastructure. The operator wants to decide between FTTH or FWA.

We start by gathering the right information from different public domain sources through an automated process in our tools (AP-Jibe) to analyze the broadband infrastructure build-out requirements. The information includes maps, homes passed density, census tracks and other data. The technology of choice will drive different broadband infrastructure activities, construction, and costs. The characteristics of the area, such as the density of homes passed, plays a large role in determining the economic viability of a particular technology.

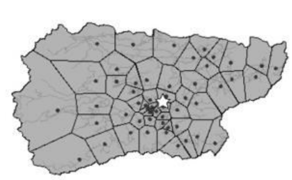
Automated Design Process

We use our specialized tools developed over years working with wireless and wireline network operators to quickly and efficiently plan broadband infrastructure projects. The goal is to support investors, service providers and governments in assessing techno-economic trade-offs. In this example, we highlight AP-Jibe® for FTTH and FWA financial network planning.

The process simply consists of three steps:

- Get the appropriate details of the market where the broadband deployments or upgrades are happening. Much of this data collection is automated from open source public databases through AP-Jibe®
- Populate and run our specialized tools to perform the techno-economic analysis for different network technologies such as FTTH or FWA
- Evaluate the upgrade costs of the deployment for the target data rate (e.g. 25/10 Mbps) in the context of technology product roadmap over a number of years (e.g. 10 years)

FTTH deployment



FWA deployment

Validated metrics. Based on our years of experience in designing FTTH and FWA networks, working with both vendors and operators, we made certain assumptions on technology deployment models and performance capabilities (table below). Such assumptions in conjunction with the AP-Jibe toolset – where we implement proprietary telecom algorithms – identify the approximate location of the node and facility placements.

Technology Assumptions	FTTH	FWA
Broadband medium	Fiber	Wireless
Deployment	Hardened node	Cell tower
Technology flavor	GPON	Mid Band 2x2 40 MHz
Homes passed per node	256	128
Distance covered	20 miles	6 miles (LOS)
Capacity per HHP Mbps	78/39	2.5/0.63

We then build detailed deployment cost model in AP-Jibe which allows us to quickly run different scenarios to evaluate different technology options deployed over different timelines.

Making the right decisions. We can make the following observations by looking at the simulation results for this example:

- FTTH is more expensive than FWA for the initial deployment
- FWA creates more nodes than FTTH
- Major cost drivers in FTTH are the underground construction and that in FWA are the operating costs

The next step in the analysis is a critical one. Here, we ask: how is this decision going to change over the next few years of operating the network? An operator or the government will come to a less informed conclusion if they do not perform the necessary analysis to answer this question.

Introducing AP-Jibe®

AP-Jibe is an integrative financial and broadband technology planning tool designed to enable access network planners to quickly evaluate access network deployment options, develop strategic technology roadmaps, evaluate different solutions and technologies and conduct detailed enterprise-level planning.

AP-Jibe provides the framework and software to perform complex network transformation planning over time with the capability to conduct scenario and what/if analysis.

The decision-making tool is valuable across the organization to benefit product strategists, operational and financial planners and supply chain professionals.

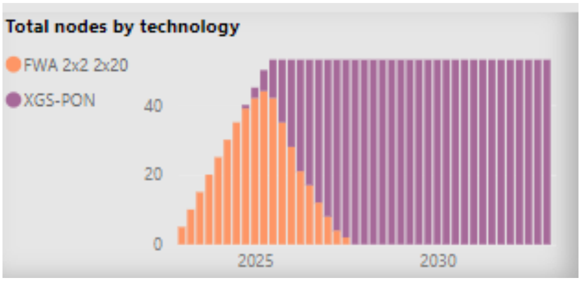
AP-Jibe is a product of our partner company First Innovations Principles (FPI).

Network evolution. An operator typically needs to upgrade their broadband access network for two reasons:

1. To meet the increasing broadband demand from consumers
2. To offer different broadband products to meet the FCC (or state) broadband definitions, to meet competitive needs, or even to retain the existing customer base

In this example, the demand is growing at 40% downstream and 30% upstream. Also, we assumed the government needs at least 25/10 Mbps broadband guarantees per subscriber; and that the operator will have a 45% take up rate, conservatively. We provide the impact of such assumptions on broadband access deployment strategies next.

Observation 1: Customer demand growth will force the operator to migrate from FWA to FTTH. The customer demand growth will require the operator to deploy FTTH over FWA technology. Even if the operator deploys FWA for an initial attractive cost reason, the operator will need to prepare for an upgrade soon enough due to high demand growth.



Observation 2: Product requirements will accelerate FWA to FTTH migration. Product requirements, such as the FCC broadband definitions, to offer digital equity, will drive the operator to upgrade the network faster than in the base case. When such upgrades are performed to migrate to FTTH, the initial FWA deployment costs are regrettable investments. So again, the question is: Is it worthwhile to go straight to FTTH in these rural communities? The answer may not be as simple as comparing the costs. Hence, we recommend investigating the operational and revenue challenges. These dimensions of analysis differ for for-profit companies versus not-for-profit initiatives.

Observation 3: FWA may be cheaper for initial deployments, but can be expensive over time. A comparison of FWA versus FTTH over 1-year, 3-year, and 5-year periods will show how the above-mentioned regrettable investments play into FWA decisions. These challenges will grow drastically if the product roadmaps are not the minimal FCC broadband definition, but the competitive speed offerings.

Observe from the comparisons below that the FWA one-year cost is lower than one-year FTTH costs, but it will be par and exceed for years three and five years.

Key Takeaways and Commercial Implications

Service providers, growth and private equity investors as well as governments have the hard task of assessing technology choices and financial trade-offs prior to finalizing investment decisions. This illustrative use case demonstrates how analytical tools help in achieving optimal decisions. The financial performance of FTTH and FWA depends on several interrelated factors that include market characteristics (subscriber density, terrain, traffic profiles, etc.) and technology parameters. In this example, we illustrated how our automated design process helps operators and state digital equity leaders to gain deep financial insight into any given target market with select technology and deployment options - in minutes – using the AP-Jibe automation tool. This enables operators or government officials, who are responsible for the deployment, to choose the right technology for the right needs. Such analysis will assist with decision-making with a 360-degree view of the risks and the rewards.

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How Mobile Network Operators Really View Open RAN

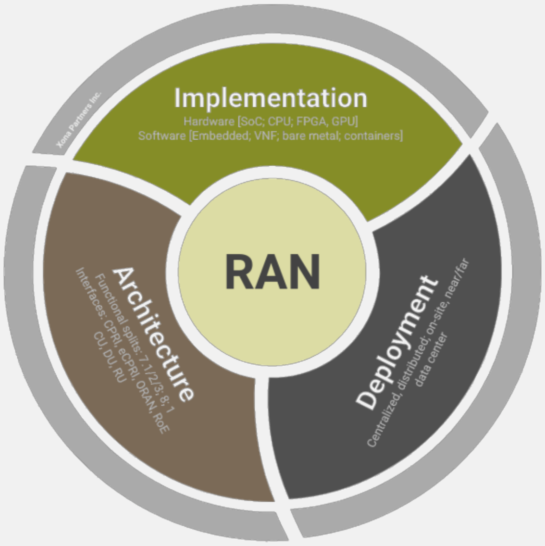
Overview. Mobile network operators present a united front in favor of Open RAN through their leading participation at the [O-RAN Alliance](), which is standardizing Open RAN interfaces, in addition to other organization such as the [Open RAN Policy Coalition]() and the [Telecom Infra Project]() (TIP). But beneath this façade, we pinpoint the difficulties MNOs have about Open RAN. The reason for this duplicity? Simply, operators seek more vendor diversity and lower equipment prices as promised by Open RAN, but recognize the flaws in this strategy. As a result, we expect Open RAN to remain a topic of interest in mobile networks for as long as funding is available to Open RAN proponents, but no meaningful deployments to happen as far as our vision extends into the future. In this, we diverge from published forecasts by market analysts. Here, we note that the market has multiple definitions of Open RAN – ours is outlined in the adjacent box "What Open RAN Is and Is Not."

US MNOs Perspective. The three incumbent US MNOs have outlined their stance on Open RAN as an architecture that could increase competition and innovation into the stagnant RAN equipment marketplace. In the process, they raised a number of challenges. The common challenge as seen by all MNOs is that Open RAN will lead to increased complexity and integration costs, especially those associated with integration *at scale* and ensuring interoperability at the level of reliability that MNOs demand. The key point to note is "*integration at scale*", and the fact that operators are playing a larger role in integration that they typically would; something that they clearly do not favor.

What Open RAN Is and Is Not

The market has multiple definitions of Open RAN – we outline ours here.

- Open RAN refers to the architecture of the wireless base station; specifically, it means open, standardized and interoperable interfaces among the base station subsystems and between the base station and other nodes or functions in the network.
- Vendor interoperability is a key element of Open RAN: any subsystem from vendor A (e.g. a radio unit) could be substituted with a similar subsystem from vendor B.
- Open RAN does not mean disaggregating hardware from software. Such disaggregation is an implementation option of the base station architecture. This is where our definition diverges from that of several industry players.
- Open RAN should not be confused with virtual RAN (vRAN) where functions run in software over commercial hardware. Thus, a virtual RAN may be Open RAN if it features open, standardized and interoperable interfaces; or may otherwise be proprietary.



Verizon calls Open RAN a 'complex technical journey' with 'much work' required for seamless interoperability and reduced complexity. Immature specifications and solutions raise IPR infringement risks. This makes access to standard essential patent on Fair, Reasonable and Non-Discriminatory (FRAND) critical to limit IPR uncertainty that delay the development of new technologies. Verizon links Open RAN with virtual RAN and makes the argument that "Open RAN is not intrinsically more or less secure than vertically integrated RAN." In all, Verizon prefers to procure Open RAN solutions from its existing vendors, rather than engage with new vendors since this will make it easier to interoperate with legacy 4G systems and to optimize performance.

AT&T raises the concern of integrating Open RAN with "the already massive investments in existing infrastructure while simultaneously maintaining, at scale, the same high levels of reliability, integrity and performance customers expect." AT&T accepts that Open RAN requires more management. However, it does question the reliability, integrity and performance of Open RAN in the context of its customers' complex requirements. AT&T states that more work is necessary to ensure that Open RAN can meet AT&T's complex feature set. This sounds to us like the death knell for most Open RAN vendors who are simply too small. AT&T sees Open RAN as being challenged to meet the "high performance requirements of large, concentrated and congested areas." However, it does recognize that Open RAN could enhance network security by being flexible, although there is a security risk associated with new vendors with shorter business track record.

T-Mobile takes the most hardline of any US-based operator against Open RAN and asserts that the technology is not mature with "implementation of Open RAN by industry is still years away." It goes to say that "fully deployed Open RAN-based mobile networks in the U.S. in the near-term are only speculative at best," and that "it may not be possible to implement the technology in existing 'brownfield' networks, where deployed RAN components were not intended to operate in a multi-vendor environment and it is likely to be more costly to do so." Among the many misgivings by T-Mobile there is the concern of roadmap and product lifecycle alignment among multiple vendors which could lead to lower performance and security inconsistencies. Further to the security challenge, T-Mobile warns that additional interfaces, functions and functional splits expand the surface of the threat. Lastly, T-Mobile dismisses any cost advantage of Open RAN citing that the cost of equipment is only a fraction of the overall costs an operator incurs, and that any reduction in equipment cost should be assessed in the context of more complicated and slower network implementation.

Dish Networks has embarked on deploying Open RAN based on a combination of over 20 vendors that include Mavenir and Rakuten/Altiostar (baseband) and MTI, Fujitsu and NEC (radios). Deploying Open RAN is a strategic choice by Dish to differentiate its network technology in a mature market dominated by intractable incumbents. The premise is that a more flexible network architecture that combines Open RAN

Challenging A Common Open RAN Misconception

There is a belief that Open RAN leads to vendor diversity and lower-cost equipment. We challenge this belief which we think is unfounded.

We suggest that Open RAN cannot stimulate a multi-vendor environment for the fundamental reason of margin stacking.

In a multivendor environment, each vendor will be seeking sufficient profit margins leading to margin stacking and higher prices to MNOs who have to factor additional costs, such as that of system integration.

RAN players are bound to vertically integrate across the RAN element stack to reduce COGS and improve margins while offering the MNOs a better price. In other words, the Open RAN market structure will revert to a few dominant, vertically integrated vendors.

vendor diversity with virtual RAN disaggregation of software from hardware would provide Dish an edge in performance and services. Dish makes different arguments in favor of Open RAN including enhanced spectrum utility, security, and national security of the United States.

Field developments point to Dish becoming bogged down in system integration. Chairman Charlie Ergen said in February, 2022: “Ultimately, we found that we had to become the system integrator, it wasn’t a role we thought we were going to take on. But with all the vendors, somebody’s got to be the middle man between there and the glue that holds them together. And we’re much more involved in that than maybe we thought we were going to be.”

Among the challenges Dish faced is implementing features such as E911 in a multi-vendor environment – an issue that T-Mobile had raised.

Recently, Dish quietly substituted Rakuten with Samsung – a more established vendor of proprietary RAN solutions and a promising portfolio of Open RAN products. It is our belief that Samsung will bring much needed stability and ‘muscle’ into Dish’s vendor and system integrator ecosystem. It makes us want to raise the question on whether Open RAN has indeed failed to deliver!

The Perspective of Asian MNOs. Japan is a key Open RAN hub with ***Rakuten*** claiming the first deployment of the architecture. However, Rakuten’s LTE network is not based on O-RAN Alliance standards. Rather, it is an integration of Altiostar’s baseband with Nokia radios. Moreover, Rakuten has only 1 LTE carrier of 2x20 MHz, which is a basic configuration that lacks the scale of incumbent operators. Rakuten has both C-band and millimeter wave frequency spectrum, but we noticed that they have not scaled the 5G C-band deployments according to the plan they presented to the MIC. By the end of 2021, Rakuten deployed ~1,030 5GNR C-band base stations (3,092 RUs) versus 3,409 planned.

Rakuten’s acquisition of Altiostar makes it a vendor. Much of their vocal support for Open RAN should be seen from that perspective. Rakuten concluded agreements with different companies to supply radios including NEC and Fujitsu which positions the Japanese vendor ecosystem in a leading position to provide Open RAN solutions.

NTT Docomo has been active in leading its vendor ecosystem to collaborate to develop RAN solutions. This is largely due to the Japanese vendor ecosystem lacking a telecom equipment manufacturer with end-to-end network elements. Thus, Docomo is one of the few operators that truly knows the complexity of integrating Open RAN solutions. But NTT Docomo is more interested in virtualized Open RAN solutions and requires the standardization of the software-hardware disaggregated elements and interfaces.

The Perspective of European MNOs. All the major European MNOs – Vodafone, Telefonica, Orange and Deutsche Telekom – have engaged in testing Open RAN. Of these, Vodafone and Telefonica are the most vocal in their support for Open RAN.

Vodafone relied on Huawei for a large part of its RAN, which became a problem with the UK government mandate to rip and replace Huawei equipment by 2027. Moreover, Vodafone is seeking to minimize capital and operational expenditures for network upgrades – which means reducing tower climbs to replace radio – while maintain legacy 2G/GSM technology. In this, Vodafone is similar to other major European MNOs with relatively small home markets and operating companies in other countries to achieve scale. Thus, Vodafone is pressured to arrive at a scalable RAN solution that liberates it from the prospects of vendor lock while at the same time the solution could cater to different requirements of its sprawling assets. The challenge for Vodafone and Telefonica is that 2G and 3G technology will remain operational in many of their markets, which requires Open RAN suppliers to develop and deliver antiquated technology. To replace all operating networks with backward compatible Open RAN networks is a major challenge that we do not foresee happening.

Both Vodafone and Telefonica continue to invest in Open RAN and to announce commitments to deploy it. But much of these commitments are focused on rural areas and emerging markets that are used as test beds.

Key Takeaways and Commercial Implications

1. Incumbent operators favor Open RAN as a solution provided by their existing vendors – not new emerging ones. They see standard-based and interoperable interfaces as an insurance policy against vendor lock at some future point in time. Incumbent operators view new telecom equipment vendors as too small and risky to supply solutions for concentrated and congested areas.
2. Integration at scale is a major detraction for Open RAN. Operators don't want to take on a system integrator role – in fact, most cannot afford it and don't have the capability and skillset to execute on it. Integration at scale has many different aspects covering the entire product development, deployment and operation phases.
3. Operators have made extensive investments into 4G networks. 5G is tightly coupled with 4G networks such that incumbent vendors have an advantage. We have seen operators who selected a new 5G RAN vendor ripping and replacing the 4G RAN equipment to ensure seamless operation and optimization of the combined network. This will harm the chance of Open RAN deployments as most large and influential operators around the world have already deployed 5G.
4. Open RAN became a political issue in the United States because there are no incumbent American RAN vendors. Operators who are feeling the pressure from their governments are against the politicization of Open RAN. In the meantime, operators are bending in the direction of the political winds looking to make the most gain by pressuring their incumbent vendors.
5. Lastly, Open RAN became a field of geopolitical confrontation between the US and China. But everyone forgets the contribution of Chinese companies to the Open RAN ecosystem. The politicization of Open RAN is unlikely to result in a good outcome for any party in the ecosystem.

Dispelling the Myth of Sustainability in 5G Mobile Networks: What's Worth The Investment?

Overview. We wrote this Insight Note for two reasons: 1. The rise in cost of energy threatens to stress the financial performance of service providers; and 2. We want to provide context for potential investments in power saving technologies to help investors decide which would be worthwhile. This is also a good time to note that power consumption has become a confounding issue because of misleading statements by different industry lobbying groups. Thus, we aim to explain in factual terms the depth of the power challenge that 5G raises and provide a guideline as to which areas one needs to consider investing in.

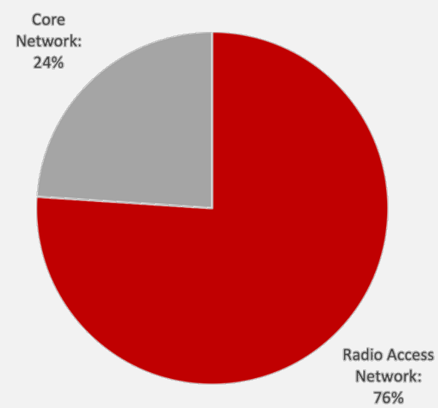
The Sustainability Challenge. Three critical factors have contributed to shaping the discussion around power consumption in telecom networks, and specifically 5G wireless networks:

1. The rise of Environmental, Social, and Governance (ESG) investing; the environmental aspect is specific to our topic.
2. The inflationary pressure in energy prices following the opening of economies post the Covid-19 pandemic.
3. Geo-political factors including the Ukraine war and US-China tensions which saw unprecedented sanctions against Chinese telecom (Huawei and ZTE) and semiconductor companies.

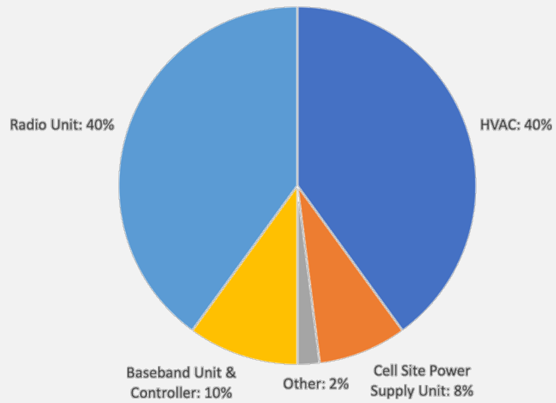
These factors came to the fore at the time mobile operators began deploying 5G technology starting in 2019. 5G practically doubles the power requirements for existing cell sites. With this backdrop, mobile network operators were silent on the issue of 5G power consumption. A quick review of

Where The Energy is Spent

The radio access network (RAN) accounts for most of the energy draw in mobile networks accounting for around 76% of the total (excludes energy consumed in offices, retail stores, fleets, etc.). Of this 76%, the radio unit of the base station accounts for about 40% of energy draw while the cell site HVAC system accounts for another 40%. Reducing HVAC requirements and improving the power efficiency of base station radios lead to significant gains in energy savings.



Allocation of Power Consumption in Mobile Network.*



Allocation of Power Consumption in the RAN.*

* Based on Vodafone reported data.

their ESG reports quickly leads one to note that much of the information they publish serves to meet the minimum regulatory requirements without providing meaningful information to assess the impact of energy on their operations. Juxtaposed to this silence, industry lobbyists were hard at work churning whitepapers and information that often have little validity. We had many discussions with industry professionals who were bewildered by the confounding information disseminated by industry players.

Dispelling the Myths Around Energy Consumption. There are three facts to note about energy consumption in mobile networks.

Fact 1: 5G consumes more power than 4G in absolute terms. This is simply because energy consumption is directly proportional to the carrier bandwidth. Additional factors that determine the power budget include the number of transmit antennas, the frequency band, and implementation options. 5G uses wider channel bandwidth – typically 100 MHz in mid-band spectrum whereas 4G/LTE is based on 20 MHz channel. Given a certain power spectral density limit (Watt/MHz), 5G uses more power (W) by the nature of its higher utilization of spectrum.

5G has a higher spectral efficiency than 4G/LTE (bps/Hz). This is the reason for the claim that 5G is more efficient than LTE as expressed in terms of Watt/Mbyte. However, the amount of spectral efficiency gain of 5G over 4G only becomes meaningful in mid-band spectrum (e.g. 2.5 GHz and 3.5 GHz) where 4G has an inefficient MIMO as well as control and signalling implementation. In low band spectrum (sub 2 GHz), the spectral efficiency gain of 5G is only about 5-10% compared with 40%-50% in mid-band spectrum.

Fact 2: Energy is a small part of operational expenditures. Mobile networks have increased in complexity over time as they grew larger to support multiple radio access technologies and frequency bands. Obviously, the larger these networks are, the greater demand for energy. Yet, the percentage of opex spent on energy is relatively small, especially in North America where the price of electricity is stable and low in comparison with that in Europe and Asia.

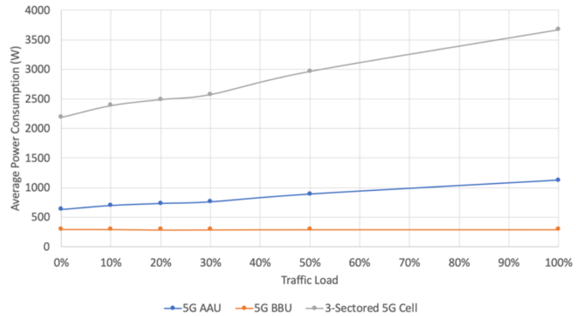
Energy expense as % of Opex[1] (2021)	
AT&T	1.1%
Vodafone[2]	2.12%
China Mobile	5.0%

As a consequence, we see Asian operators who led the deployment of 5G networks are also leaders in testing techniques to reduce power consumption. For some, such as in China, this includes a complete shut-down of the 5G network at night when traffic demand is low!

Fact 3: Using ratios such as unit of energy per unit of traffic (e.g. Watt-hour/Mbyte) is not meaningful and could even be misleading. First, the notion that energy consumption is a function of traffic is not wholly accurate. In a 5G wireless base station, the radio power consumption shows a dependency on traffic, but it is not zero when there’s no traffic. The power consumption for baseband units is relatively independent of the traffic load. Second, quoting performance in terms of Wh/MB (or similar ratios) hides the absolute amount of energy consumption, which is what really matters. This renders such ratios interesting for gauging the efficiency of successive generations of a certain technology, but not meaningful for gauging expenditures or impact on environment.

[1] Opex includes COGS, SG&A, depreciation and amortization and other expenses.

[2] Based on Vodafone reported results for fiscal year ending March 31, 2022.



Average power consumption in a 3-sector 5G base station as measured by a Chinese operator for a ZTE base station.

The Capex vs. Opex of Energy. When service providers roll out a new technology, they need to increase the power available at the cell site in order to accommodate the additional spectrum bands and equipment related to the upgrade (e.g. radios, baseband, backhaul, HVAC, batteries and power backup systems, cables, etc.). This is a capex impact. On the other hand, the cost of energy ($/kWh) is the opex portion.

5G presents a capex challenge because 5G almost doubles the power requirements at the cell site (depending on the amount of spectrum and operating systems). This has many operators think twice about their capacity requirements and select the appropriate equipment that best meet their cost and performance trade-offs. For instance, operators opted to deploy 32T32R radios instead of 64T64R to exchange higher capacity for lower energy requirements. In short, the capex challenge is felt more uniformly by service providers.

In contrast, the energy opex impact varies depending on several factors including foremost the cost of energy. Thus, the opex impact is regional and is felt to varying degrees by the different service providers.

Assessing Energy Efficiency Innovations. New solutions to improve the efficiency of wireless networks are available. They could be categorized under hardware and software solutions. These solutions include, for example, semiconductor devices and processor accelerators to improve the efficiency of radio and baseband units. They also include software techniques that partially or fully power down certain resources. Moreover, the advent of Open RAN led to the rise of several new companies developing RAN subsystems such as remote radio units and virtualized baseband units, in addition to companies developing software applications that make use of the newly standardized base station interfaces. While it is not our objective to expand on energy saving techniques here, we wanted to provide investors a framework to evaluate the potential impact of such technologies.

The simplified framework maps the energy impact onto the financial impact for the service provider to assess the level of traction a solution could achieve. It is important to note that this framework is one in a tool kit, so it needs to be considered as part of a process: it gives visibility into only one aspect among many that cannot as well be ignored.

		Financial Impact	
		Opex	Capex
Energy Impact	Peak		Hardware solutions
	Average	Software solutions	Hardware solutions

Solutions that address the peak-power demand in wireless networks have first priority. They help reduce both capital and operational expenditures, thus they have the most impact. Typically, such solutions are hardware solutions that include semiconductor technologies, lithographic process technology, amplifier linearization and compensation techniques and radio architecture and design. All service providers would be interested in such solutions since the benefits are immediate and relatively easy to quantify. However, the interest is highest during the network refresh cycle where there is a high certainty of the business case.

Software solutions, including the use of AI technology, come in second order of interest since they affect the average energy consumption and have an impact on opex, but limited if no impact on capex (since they largely don't impact peak power consumption). Such solutions are often traffic dependent and include some type of powering-down resources to save energy (sleep modes). Thus, they lead to loss in capacity. Service providers in high energy-cost areas, such as Asia and Europe, would value these technologies more readily because the threshold for a positive business case is lower. To illustrate, a 25% savings in the electricity bill reduces China Mobile's opex by 1.25%, whereas the same savings would only shave 0.28% off AT&T's opex. Therefore, operators paying high prices for energy are the most amenable to trade-off capacity for power savings.

The framework explains China's leadership in field testing and implementing software-based techniques to minimize the power consumption in 5G networks. As an interesting related note, the leading position Huawei and ZTE have in designing power-efficient radios would erode because of their inability to access the semiconductor devices necessary to remain at the leading edge of the power efficiency curve.

Key Takeaways and Implications

1. Power consumption accounts for a relatively small percentage of a service provider's operational budget with large geographic variance: order of 1% in North America up to 5% in China with Europe's energy cost rapidly spiraling upwards.
2. All service providers would be equally interested in reducing peak power requirements of new radio access technologies. This saves both capital and operational expenses. Peak power is typically related to hardware technologies especially in the radio unit which accounts for a large part of the base station power consumption.
3. Service providers in high-energy cost areas such as China, and now Europe, would be most interested in software-based solutions. These solutions impact the opex spent on energy and involve trading off capacity for lower power consumption.
4. The framework of peak/average energy vs. capex/opex financial impact serves the purpose of predicting the rate of adopting new technologies and by whom. However, we note that this framework is only one in a set of tools we use in evaluating such investments and market evolution.

About Xona Partners

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Enterprise Private Wireless Networks: 5G or Wi-Fi?

Overview. Private networks (PNs) promise to generate new revenue streams for mobile network operators, as well as cloud players like AWS and Azure who invested heavily in developing their own PN service offering. However, 5G is not the only technology competing for this market segment. While 5G received the most attention, Wi-Fi remains entrenched in the enterprise market. Moreover, the technology roadmap for Wi-Fi addresses many of its shortcomings and raises its viability versus 5G.

In this note, we compare and contrast Wi-Fi and 5G to better understand the prospects for each technology in the enterprise digital transformation process.

Enterprise 5G Networks. Using cellular technologies for enterprise networks dates back to the mid-2000's when a new generation of broadband technologies emerged (e.g. LTE). The barriers to adoption then, and to a lesser degree now, are spectrum, cost and complexity (or the SCC!). Cellular technologies operate in licensed spectrum; scale to service millions of subscribers; and offer thousands of configuration parameters for experts to optimize the performance of a complex heterogenous network. This is hardly the recipe enterprises need.

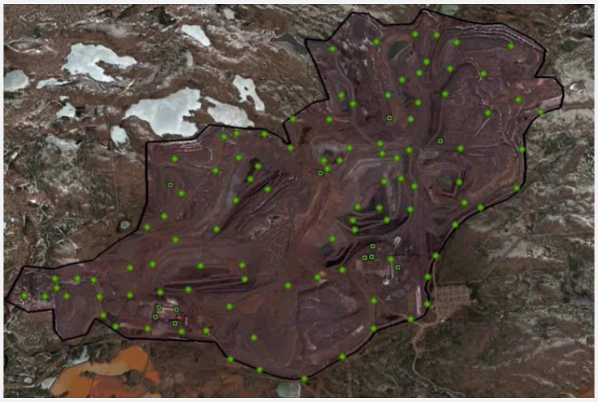
5G introduced a flexible architecture to enable different deployment and business models leveraging innovations in virtualization and automation to reduce capex and accelerate service enablement. Regulators for their part are making spectrum available for PNs, although the efficacy of such regulations is debateable.

The combination of the aforementioned factors attracted interest in 5G private networks from a range of players in addition to the mobile network operators (MNOs): Cloud players (AWS launched their own service in the US in CBRS band; Microsoft

The Cost of Private Networks

The Total Cost of Ownership (TCO) is one of a few elements that determine the suitability of a technology in a certain use case. 5G equipment is more expensive than Wi-Fi; and is more complex to configure and manage. Yet, 5G provides long range, so a single 5G cell could replace several Wi-Fi access points. Thus, it could be cheaper to deploy 5G especially in open areas where the cost of Wi-Fi could quickly inflate considering the additional cost of towers, backhaul, equipment and support services.

This highlights the necessity to take a wholistic view in evaluating technologies. No technology is superior to another in all use cases and applications. While there are areas of overlap, each would have a niche where it excels.



Wi-Fi mesh network in open pit mine with ~100 APs covering an area of 2 km2, or roughly 80 m cell range. It is possible to cover the entire area with 1 LTE site!

Azure made multiple telecom acquisitions to structure its offering), system integrators, niche vendors with innovative small-scale networks to compete with the incumbent telecom equipment vendors whose margins come under pressure in small enterprise deals.

Wi-Fi Evolution. Since Wi-Fi was first introduced in 1997, the 6th generation of Wi-Fi (802.11ax) is now commercially available. Unfortunately, experience biases our judgement of Wi-Fi: We accept its lower quality of service in exchange for cost-free access. But past experience could be misleading considering the evolution of Wi-Fi towards the 6th and 7th (802.11be) generations.

Wi-Fi 6 and 7 introduce features that address many of the shortcomings of prior generations that result in poor performance under network load. Beginning with Wi-Fi 6, a number of new features will boost the performance to accommodate applications with stringent latency and throughput requirements (e.g. AR, VR, etc.). This makes Wi-Fi a credible competitor to 5G in many applications, including those requiring millisecond-scale latency.

The strength of Wi-Fi remains in being a well-established technology in the enterprise. As such, it does not require re-engineering or redesigning the IP network and cybersecurity architecture as is the case in 5G. In fact, having deployed 5G private wireless networks, we find that integrating 5G PNs into the enterprise cybersecurity architecture is one of the most complex activities. Moreover, operating PNs in unlicensed spectrum has both benefits (spectrum availability) and drawbacks (interference in shared spectrum). Congestion and interference would ease with 1,200 MHz of new spectrum in the 6-7 GHz band recently made available in North America and a few other markets[1]. However, the channel bandwidth is also increasing which further accentuates the availability challenge.

Supporting Long Range Communications

A number of features combine to support communication over long distances. Perhaps the most obvious feature is the transmitter output power. Wi-Fi is limited by regulations to transmit at ¼ W in most unlicensed bands with some exceptions where higher power is allowed. But even then, it cannot match the power limit of licensed spectrum where 5G operates (tens of Watts). Other parameters include receiver performance and channel coding among others.

Another critical factor is the design of the physical layer (PHY). We highlight this because while one could conceive of workarounds to address other limitations, it is not possible to change the PHY architecture which is built into silicon.

Communication signals take multiple paths to travel between a transmitter and a receiver. This results in multiple versions of the same signal arriving at different time intervals. The superposition of these signals leads to “inter-symbol interference” (ISI).

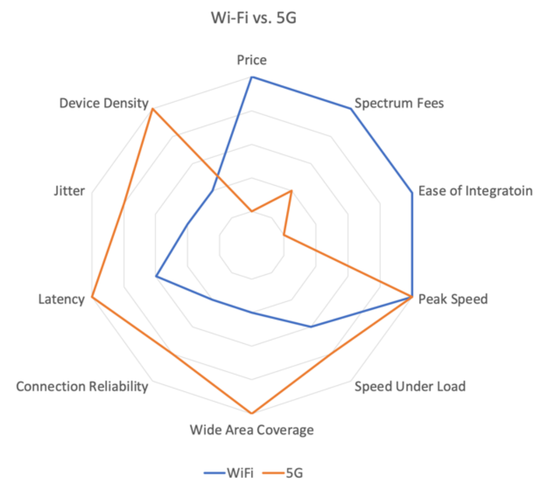
The solution for ISI is adding a time buffer between the symbols so they don’t interfere with each other. The longer the buffer, the longer the range of communications, and the lower the throughput. This buffer is called the Cyclic Prefix (CP).

Typical CP in 5G is 4.69 μsec with several shorter options available. In contrast, Wi-Fi supports 0.8 μsec with later generations adding the option for 1.6 and 3.2 μsec. Thus, one can readily see that Wi-Fi is inherently designed to support local area networks with a roadmap to increase range, while 5G is meant for wide area networks.

[1] Countries that released 1200 MHz include the US, Brazil, Canada, Japan (most recently), Korea and Saudi Arabia. The UK and Australia released 500 MHz while the EU adopted 480 MHz. China is notable for not deciding yet, with a possibility it may allocate the spectrum for 5G/6G mobile networks.

Comparing 5G and Wi-Fi. 5G has clear advantages in providing long-range of coverage and mobility services over wide areas. On the other hand, Wi-Fi has clear advantages in its simplicity of deployment and integration into enterprise networks.

5G leads on some performance parameters such as latency and device density. However, such an advantage is tempered with the evolution of Wi-Fi standards to support Industrial IoT (IIoT) and time-sensitive networks (TSN). Wi-Fi 6 is already capable to provide 10-20 msec latency. Wi-Fi 7 is designed to further reduce latency to below 10 msec. This is possible through a number of enhancements, such as Coordinated OFDMA introduced in Wi-Fi 6 and QoS management features introduced in Wi-Fi 7 to support TSN.



In this comparison, the outer circle is "better" while the inner is "worse". Note that this comparison is for "typical" implementation of the technology, while it is possible to optimize performance in the future to improve the standing.

Practical Matters. Both Wi-Fi and 5G standards provide a wide array of features. This is different from what vendors implement and sell. Ultimately, the products most in demand will have the lion's share of the market. Large vendors dominate such mainstream markets. Consolidation is a feature in both 5G and Wi-Fi equipment markets where a few vendors have the lion's share of revenue; especially in cellular networks where the top 3 vendors account for over 70% of market share.

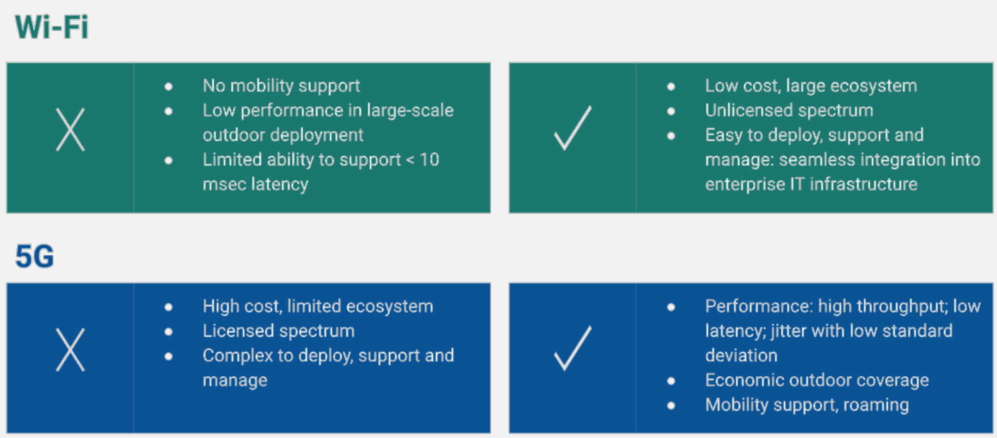
	Wi-Fi 6/6E (802.11ax)	5G
Modulation	Up to 1024 QAM	Up to 256-QAM
Access technology	OFDMA	OFDMA
MIMO antennas	Up to 8T8R; 8 streams	Up to 64T64R; 4/8/16 streams
Channel bandwidth	20/40/80/160 MHz	20/40/80/100 MHz
Coverage range	Indoor: 50 m Outdoor: 300 m	Outdoor: 100m (small cell) 100 km (macrocell)
Latency	20 msec (avg) 10 msec (priority scheduling)	10 msec (avg, MBB) 1 msec (uRLLC)
MAC	Contention-based CSMA/CA	Slotted
Spectrum	Unlicensed; 2.4 GHz, 5 GHz, 6 GHz	Licensed; sub 2 GHz; mid-band: 2.5/3.5 GHz; mmWave: 26/28 GHz
Guard interval (CP)	0.8/1.6/3.2 μsec	4.69/2.34/1.17/0.57/0.29 μsec
OFDM symbol time	12.8 μsec	66.67/33.33/16.67/8.33/4.17 μsec
Security authentication	EAP-TLS (certificate); EAP-PEAP (username/password); EAP-AKA (SIM)	5G-AKA; EAP-AKA
Encryption	AES 256	AES 256
Installation skill level	Low	High
Management complexity	Low	High

Private networks, whether based on Wi-Fi or 5G, allow vendors to customize solutions for specific market segments. This is beginning to happen: for example, Verizon's private network offering features solutions from Ericsson, Nokia and Celona targeting high, mid- and low-market, respectively.

Another practical issue is the support systems necessary to enable private networks. Support systems complexity and cost. For instance, the cybersecurity architecture is an integral part to these networks and its cost is often missing from the original business case. Another example is that of low latency applications which require accurate synchronization and timing mechanisms beyond the requirements of public networks. Latency is taken for granted in 5G networks, but the truth is that it requires additional capex.

Key Takeaways and Implications

Wi-Fi is optimized for local area coverage in unlicensed spectrum, whereas 5G is optimized for wide area coverage in licensed spectrum. Both technologies are implementing options to extend usability into adjacent markets. Thus, Wi-Fi is incorporating features to support greater mobility and extend range; while 5G is seeking to reduce the cost of the end-to-end network through virtualization. Both will compete and complement each other in the enterprise private wireless market leveraging their strength accordingly.



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AST SpaceMobile: Can Technology Overcome Commercial Challenges?

Overview. AST & Science has a bold plan to provide direct satellite-to-handset service (DTH). The scale of technical and commercial challenges is high. This Insight Note highlights a few of the critical aspects that impact AST's success. On the technical side, the antenna system that AST developed to meet a very challenging connectivity equation is critical. On the business side, securing revenue in the context of partnership with mobile network operators and necessary regulatory permits will determine AST's future success.

Constellation Plan. AST plans a constellation of 243 satellites in low earth orbit (LEO) at an altitude between 725 and 740 km. The satellites will be deployed in 15 inclined orbits of either 40 or 55, in addition to an equatorial orbit with 20 satellites. Global coverage is possible with 110 satellites. AST has mentioned capability to deliver a throughput of up to 30 Mbps.

AST launched its BlueWalker 3 (BW3) test satellite on September 10, 2022 using SpaceX Falcon 9 rocket. BW3 weighs 1.5 tons and features a 64.4 m^2 phased-array antenna. This mammoth antenna is a critical part to enabling DTH services at scale; it is what sets DTH satellites apart from the ones catering to fixed wireless access use case (e.g. Starlink), or backhaul (e.g. OneWeb, Telesat). Testing with MNOs is expected to start in by the end of 1Q23 or early 2Q23.

AST plans to lunch 6 of its production-grade satellites, BlueBird, by end of 2023 and 15 in 2024 to complete the equatorial plane first. The BlueBird satellites are larger and heavier than BW3.

Company Overview

AST was founded in 2017. It became a public company in April 2021 after merging with a special purpose acquisition company (SPAC) which raised about $462 million. Vodafone, Rakuten and American Tower count among its investors.

AST has strategic partnerships with AT&T, Vodafone and Rakuten. It signed Memorandum of Understandings (MoUs) to test the system with a number of service providers including Orange (testing in an African country), Telefonica (Latin America), MTN (Africa), Globe & Smart (Philippines), Smartfren (Indonesia) among others.

Network Parameters

User link - 3GPP cellular, PCS and AWS bands

- Downlink: 617 – 960 MHz; 1930 – 1990 MHz; 2110 – 2180 MHz
- Uplink: 663 – 915 MHz; 1710 – 1780 MHz; 1850 – 1910 MHz

Gateway links – V band

- Downlink: 37.5 – 42.5 GHz
- Uplink: 45.5 – 51.4 GHz

Access technology: 2G, 3G, 4G and 5G

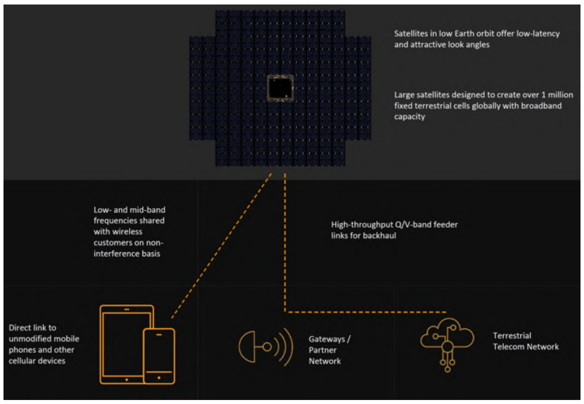
Channelization: 10, 5, 3, 1.4 MHz

Peak antenna gain

- Cellular bands: 41 dBi
- PCS/AWS bands: 47 dBi

Transmit power per beam: 20 W

Closing the Link. The challenge in DTH communications is that the user device has a low-gain antenna and relatively low transmit power (see technical corner for details). This places the burden on the satellite to compensate for this weakness through a high-performance antenna system. The antenna system is additionally critical to mitigate co-channel interference to adjacent service areas.



AST architecture showing wireless base stations on Earth. AST plans to interface with Nokia and Rakuten base stations. [Source: AST]

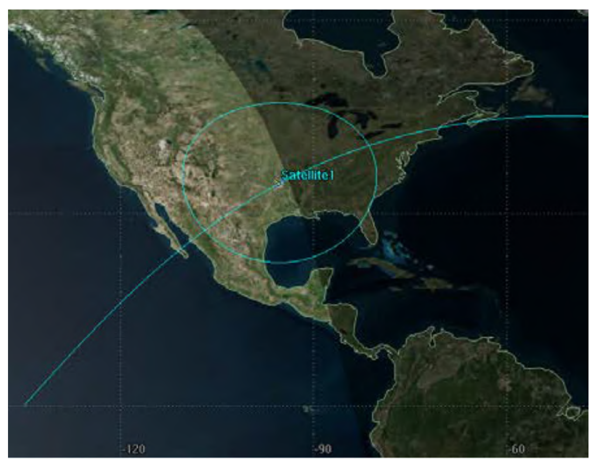
AST designed a unique phased-arrray antenna capable of providing up to 2800 user beams (likely BW3 supports a lower number perhaps up to 580 beams). Each beam could be electrically steered to point in a Field of View (FoV) of 20° elevation angle. User beams can track a small ~24-km diameter fixed-cell on earth within its FoV without steering the boresight of the planar phased array antenna. A cell could be illuminated by multiple beams to improve capacity and user throughput. Users could be handed over between beams on a break-before-make basis. Each satellite will

BW3 693 sq. ft. phased-array antenna. [Source: AST]

provide service up to 58 degrees away from boresight.

The size of the antenna has raised concerns on structural dynamics and integrity for operation in space over the lifetime of the satellites (7-10 years) and subsequent de-orbiting. Additionally, the power budget is critical since the transmit power per beam is 20 W.

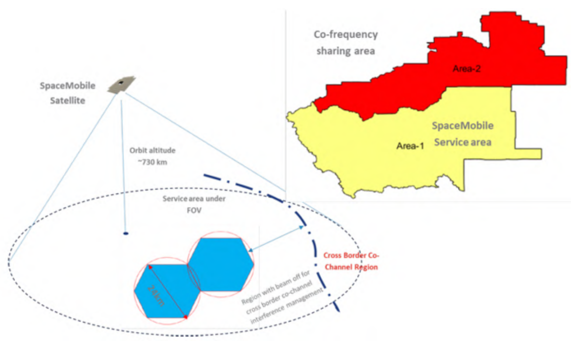
Spectrum Subordination. AST needs to subordinate, or enter into some form of agreement, with mobile network operators to access their spectrum. This would require regulatory approvals since the spectrum is designated for terrestrial mobile service. The operation of DTH satellites requires modifying the Tables of Frequency Allocations to include Mobile Satellite Service (MSS). In the United States, several parties objected to AST's license applications including mobile network operators (Verizon, T-Mobile) on the premise of interference from AST satellites to their mobile subscribers.



Coverage footprint for AST satellite. [Source: AST]

Interference Scenarios. Of the different types of interference that's possible, downlink co-channel interference from AST to adjacent market operators at the boundaries of service areas has raised concerns. The antenna intends to fill the coverage holes with its small cells while keeping away from illuminating adjacent markets by backing off the transmit power or tuning off beams near adjacent service area boundaries. Spectrum management is especially important over territories covered by relatively small license service areas.

To further highlight, the satellites are in motion at speed close to 7.5 km/sec – i.e. they circle the Earth every ~99 minutes. This underscores the critical nature of resource management and control functions necessary to maintain service continuity and mitigate interference to adjacent markets.



Co-channel interference to adjacent service area. [Source: AST]

Commercial Risks. Capital expenses in DTH constellations include that of satellites, launch and ground stations. The absence of cost for user terminals helps to uplift the business case in comparison with constellations catering to fixed wireless access or data backhaul applications.

The large and heavy satellites along with the 7-10-year replenishment cycle means that satellites and launch services is where a large percentage of the cost reside. The satellite payload and antenna are very complex systems – AST has invested over $92 million in capital expenses on R&D for BW3 to date. It also expects that the first 20 satellites to cost $320 m to build and launch ($16 m/satellite). Supplementing the constellation with 90 satellite to provide

Technical Corner

One of the main questions related to AST is whether it could deliver high throughput to users. AST claimed a peak of 30 Mbps. We analyzed ASTs filings for the RF performance on which we form our opinion.

The downlink peak EiRP at 90° elevation angle is 50.4 dBW per carrier. The path loss is 156.2 dB for AWS-band frequencies. The power at the receiver input of the phone is -75.8 dBm. This leaves a margin of 19.6 dB for SNR.

At first glance, this SNR should support 64QAM modulation. Therefore, under ideal conditions in open areas, it should be possible to provide 30 Mbps in a 10 MHz terrestrial LTE or 5G carrier.

In practice, the throughput would be lower (and a lot lower!). We need to account for additional margins for fading, interference and other losses due to signal obstructions. There could also be other losses introduced by design to compensate for the long distance between the satellite and phone. Enhancing the signal reliability means decreasing the effective throughput of the system.

To further improve throughput, AST plans to upgrade the first-generation single antenna systems (SISO) with multiple antenna systems (MIMO). Since MIMO provides gain in a multipath channel that is not present in line-of-site point-to-point communications, it would require a novel implementation. While we don't know how AST intends to implement MIMO, we could foresee an attempt to leverage multiple satellites to deliver on the necessary decoupling of communication channel. This approach adds a lot of complexity in terms of timing and synchronization of the signals in addition to increasing the complexity of traffic management.

global coverage will likely cost at least an additional $1 B.

The cost structure makes revenue the critical aspect for a positive business case. AST would share revenue with the MNOs in exchange for the rights to operate in their spectrum. MNOs will also need to collaborate with AST on ground station connectivity where we envision the need for geographic redundancy that would allow AST to maintain the performance integrity on the feeder links.

Overall, the commercial risk is whether there's sufficient revenue opportunity for AST to be able to recover its investment. On this, we don't believe that "connecting the unconnected" in the equatorial belt covered in the first phase by 20 satellites is what can carry a positive business case. Deploying global coverage will be necessary; and in this AST will share the market with other constellations – Globalstar, SpaceX (following T-Mobile announcement) and Lynk.

Key Takeaways

Direct-to-handset satellite connectivity is technically and commercially challenging proposition. On the technical side, the satellite needs to compensate for the limited capability of the mobile handset, which is only possible through a high-gain antenna. The antenna AST is developing could in theory meet Its 30 Mbps target, but in practice the effective throughput would be lower by as much as half, if not more. Additional technical risks include traffic, resource and antenna management which are critical to the performance of the system, as well as the power budget. The implementation of MIMO would be a very complex and challenging endeavor, and may likely be unpractical.

AST faces commercial risks related to subordination of spectrum from mobile network operators. This requires regulatory modification to include satellite mobile service in bands designated for mobile service. The business case sees an uplift by eliminating the cost of user terminals which is a drag on profitability of constellations focused on fixed access. The revenue side does, however, represent a challenge.