GLOBAL CELL-SITE CONSTRUCTION AND EVOLUTION STRATEGIES

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EXECUTIVE SUMMARY

5G networks are being rapidly deployed around the world with many of these networks working in parallel to existing legacy cellular technologies, such as 2G/3G and 4G, to provide higher data connections of 10X more throughput than 4G. 5G networks typically use high-frequency spectral resources (C-band and mmWave) and, according to the International Mobile Telecommunications 2020 (IMT-2020), the downlink and uplink peak data rate of a 5G network should be 20 Gigabits per Second (Gbps) and 10 Gbps, respectively, with downlink and uplink peak cell spectral efficiency of 30 bit/Second (s)/Hertz (Hz) and 15 bit/s/Hz, respectively. The use of higher frequency bands, which suffer from higher penetration loss and the continuous increase in requested data rates for end users, dictate the necessity of higher network availability and network capacity, which could be achieved through additional spectral resources and network densification. Many MNOs have already bought at auction spectrum for 5G deployment, but the network capacity can be maximized through network densification. Thus, the acquisition of cell site assets is critical for Mobile Network Operators (MNOs) for the effective performance of 5G networks.

These network requirements have brought huge challenges to MNOs, local governments, vendors, and System Integrators (SI), as some of those challenges are well-known unsolved issues evidenced by the deployment of legacy generations of cellular technologies and have become even more relevant now with the advent of 5G and the expected large-scale cell site densification.

These challenges range from the high cost associated with deploying network infrastructure at street level, to complex approval processes from local government, including lengthy and expensive site acquisition processes; lack of power availability; limited backhaul availability; lengthy planning application processes for street works or build works; limited space availability on premises and within street furniture; size and flexibility of existing cellular equipment that can fit the different rollout scenarios (*e.g.*, smaller antennas to fit within wall-mounted small cell enclosures); lack of availability of underground space for the deployment of a new chamber and ducts; decluttering policies from local governments that can largely impact the deployment of 5G networks; and increasing tenancy fees for additional 5G equipment and increased power supply.

In response to this situation, there is some pressure on telecom equipment vendors to come forward with solutions that suit each rollout scenario. Improved physical features, such as smaller form factor antennas similar to the Wi-Fi Access Points (APs), lighter-weight and smaller Massive Multiple Input, Multiple Output (mMIMO) antennas, and an innovative variety of vendor equipment, backhaul, and reduced power consumption solutions will help MNOs address these challenges and stay ahead of the competition.

Finally, unlike previous generations of cellular technologies, policymakers, urban planners, and local governments have an important role to play, providing more flexible legislation that enable the rollout of network infrastructure at a faster speed by providing clear guidelines for easy access to the assets for the deployment of cellular infrastructure.

WORLD-WIDE CELL-SITE DEPLOYMENT TRENDS & STATUS

MARKET OUTLOOK

MNOs have started to roll out 5G networks across different regions around the world. China has deployed more than 500,000 5G base stations among the three big MNOs: China Mobile, China Telecom, and China Unicom. In the United States, AT&T has claimed 5G network availability nationwide, Verizon has launched 5G ultra-wideband in parts of more than 30 cities, and T-Mobile and Sprint have joined forces to build 5G networks and plan to provide 99% 5G coverage to Americans within 6 years. In the United Kingdom, various MNOs have rolled out 5G networks in different cities. For example, EE has rolled out 5G networks in 80 cities, Vodafone in 44 locations, Three in 65 cities, and O2 in 60 cities. Similarly, in Australia, Telstra coverage has expanded to 10 major cities, and in Germany, Vodafone and Deutsche Telekom have launched 5G in several locations. In South Korea, SK Telecom claims to have the world's first nationwide commercial 5G wireless network.

In order to boost 5G coverage and achieve the required network capacity in the most cost-efficient way, MNOs are undertaking cell site upgrades to incorporate 5G. According to U.S operator T-Mobile 1,000 sites and towers are being upgraded each month.

However, physical site densification is still required to increase the amount of available capacity in the cellular network. MNOs are densifying their networks by using a variety of cell site types, such as macrocells, microcells, small cell deployments, and in-building solutions. Macrocells can be deployed on different types of infrastructure, such as towers, monopoles, and rooftops. A microcell can be installed on building facades and streetlamps, while small cells are typically deployed on street furniture, such as lamp posts and bus stops, among others.

Nonetheless, asset accessibility and suitability are the two main factors that can dramatically reduce the number of viable locations. In terms of accessibility, the challenge comes from a landlord's lengthy approval process and local development restrictions. On the other hand, in terms of suitability, the challenges are associated with a cell site's lack of power, poor propagation characteristics, limited space, and a high Total Cost of Ownership (TCO).

Chart 1 and Chart 2 show the expected cell site densification for the macro and small cell layer, respectively, between 2019 and 2025. Overall, macrocell sites and small cell sites are expected to grow during the following 5 years.

According to Chart 1, the 4G macrocell site deployment is estimated to grow approximately 1.3X from 3.3 million in 2019 to 4.5 million by 2025, while 5G macrocell site deployments will grow 37.80X from 65,000 to 2.4 million by 2025. In addition, as shown in Chart 2, the 4G small cell sites are expected to grow 8.9X from 303,000 sites in 2019 to 2.7 million by 2025, while 5G small cell sites are expected to grow 239.3X from 3,000 in 2019 to 718,000 in 2025. Therefore, the acquisition of cell site assets is critical for MNOs to ensure the effective performance of the 5G networks and manage the tremendous capacity expansion expected with 5G.

Chart 1: Installed Macrocell Site by Technology and Region
World Markets, Forecast: 2019 versus 2025

(Source: ABI Research)

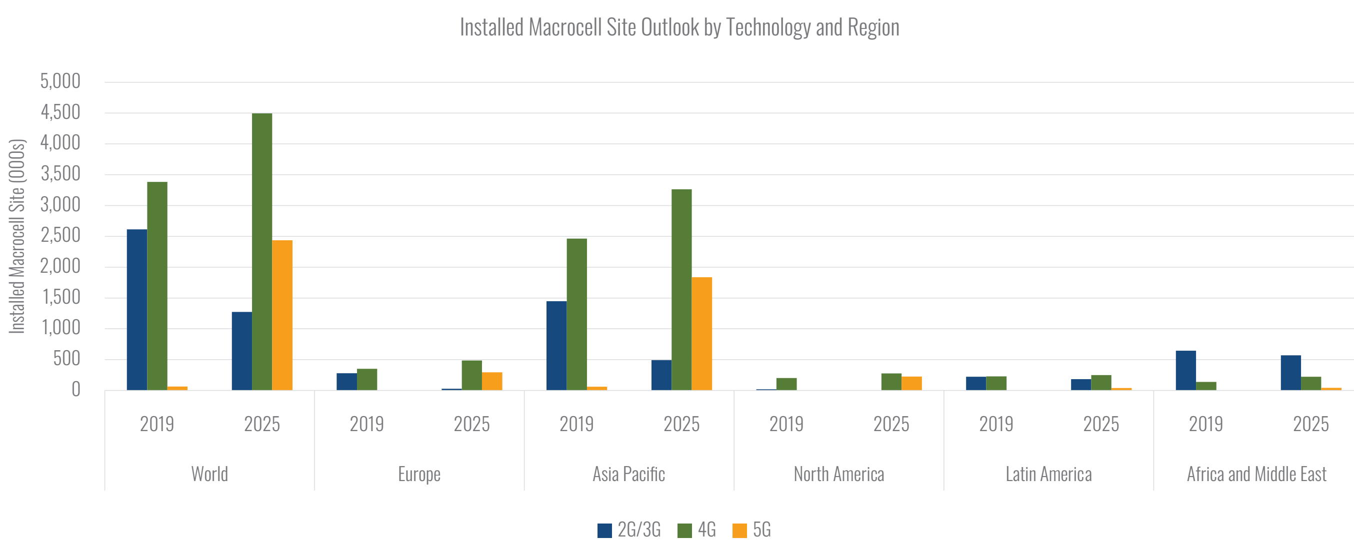
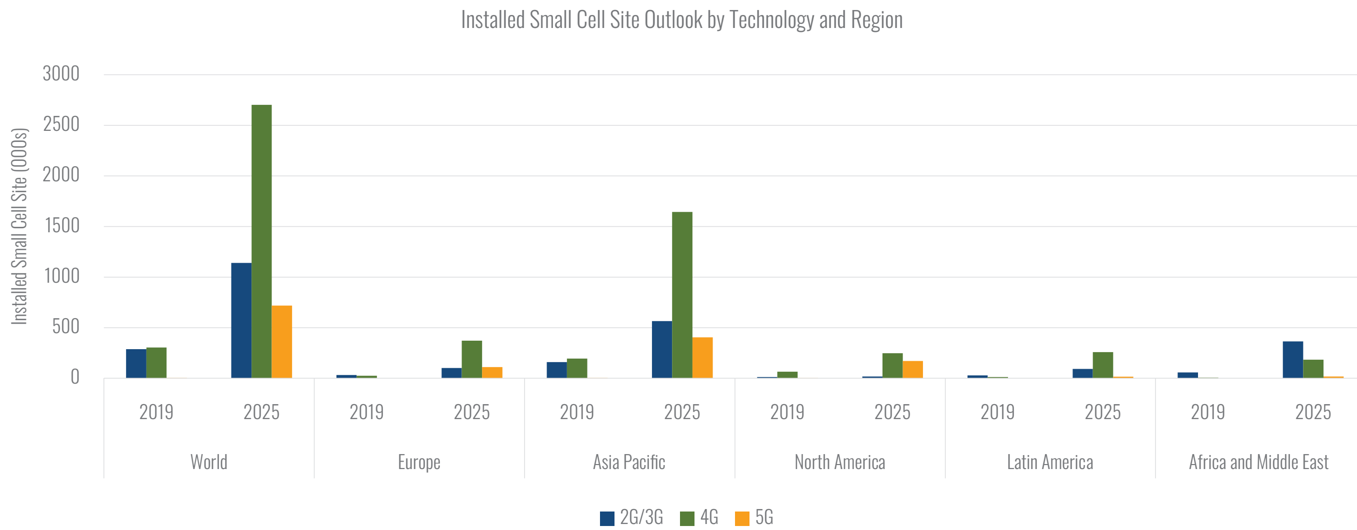


Chart 2: Installed Small Cell Site by Technology and Region
World Markets, Forecast: 2019 versus 2025

(Source: ABI Research)

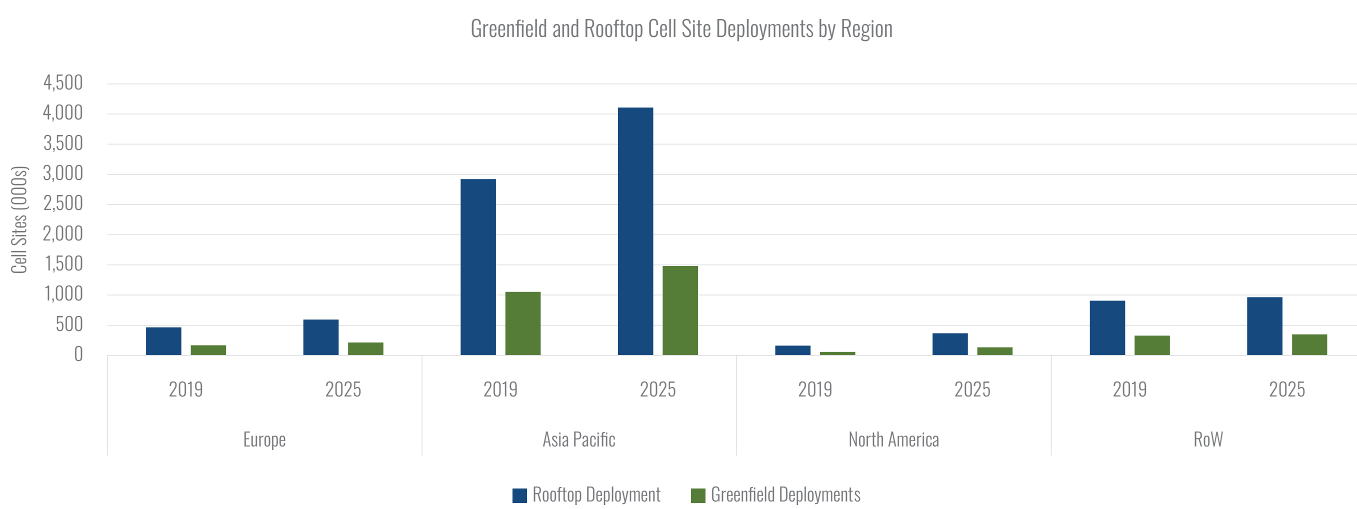


OUTDOOR MACRO-CELL

Outdoor macrocells in urban areas are commonly deployed on rooftops and monopoles compared to greenfield cell sites. Chart 3 presents the ratio of the installed base for greenfield and rooftop deployments across different regions. The deployment of greenfield infrastructure is not favored by MNOs in urban areas because it requires larger areas for installation, which limits the number of available cell site locations and affects the appearance of the city. Therefore, in metropolitan areas, MNOs have favored the deployment of rooftops.

Chart 3: Greenfield and Rooftop Cell Site Deployments by Region
World Markets, Forecast: 2019 versus 2025

(Source: ABI Research)



With the imminent rollout of 5G, MNOs have started to upgrade existing cell site infrastructure. This upgrade means that rooftops are suffering from several limitations, such as reduced site space and restricted load-bearing capacity, as additional 5G equipment increases site occupancy. Moreover, this requires extra capacity and capabilities of the communications equipment room, namely additional power supply, space, and cooling capacity, among others. To date, the communications equipment room represents a huge operational expenditure (OPEX) for MNOs due to the costs associated with rent, electricity fees, and air conditioning systems. In order to reduce OPEX and complete the 5G upgrade, MNOs have started to undertake modernization and reconstruction of indoor equipment rooms in existing cell sites. However, it is likely that the number of indoor equipment rooms will decrease as new cell sites are expected to deploy full outdoor telco equipment to further generate revenue enhancements.

Furthermore, different antenna techniques, such as mMIMO and a greater level of sectorization, are also being implemented to increase network capacity and maximize cell site infrastructure.

- mMIMO is an essential technology for MNOs. Long Term Evolution (LTE) Advanced Pro and 5G rely on high-order MIMO to scale up multiple transmissions to a particular end-user device and to handle transmissions to clusters of active end users, both indoors and outdoors. The Active Antenna Units (AAUs), such as 8T8R, 32T32R, or even 64T64R, will substantially increase the required power supply. This trend is led by the United States, followed by Europe and Asia-Pacific.
- Additional cell site sectorization fully leverages the existing site and almost doubles capacity, despite practical limitations due to interference between adjacent antennas and increased user handovers. It should be noted that high-order sectorization deployments perform best for uniform traffic distribution across the covered area. The most typical configuration is to double the number of sectors from three to six on the horizontal plane by installing narrow beam antennas. However, there are indications that MNOs are upgrading from 6 sectors to 9 and there are also deployments of 12-sector cell sites.

SMALL CELL (POLE-SITE, MICRO-CELL)

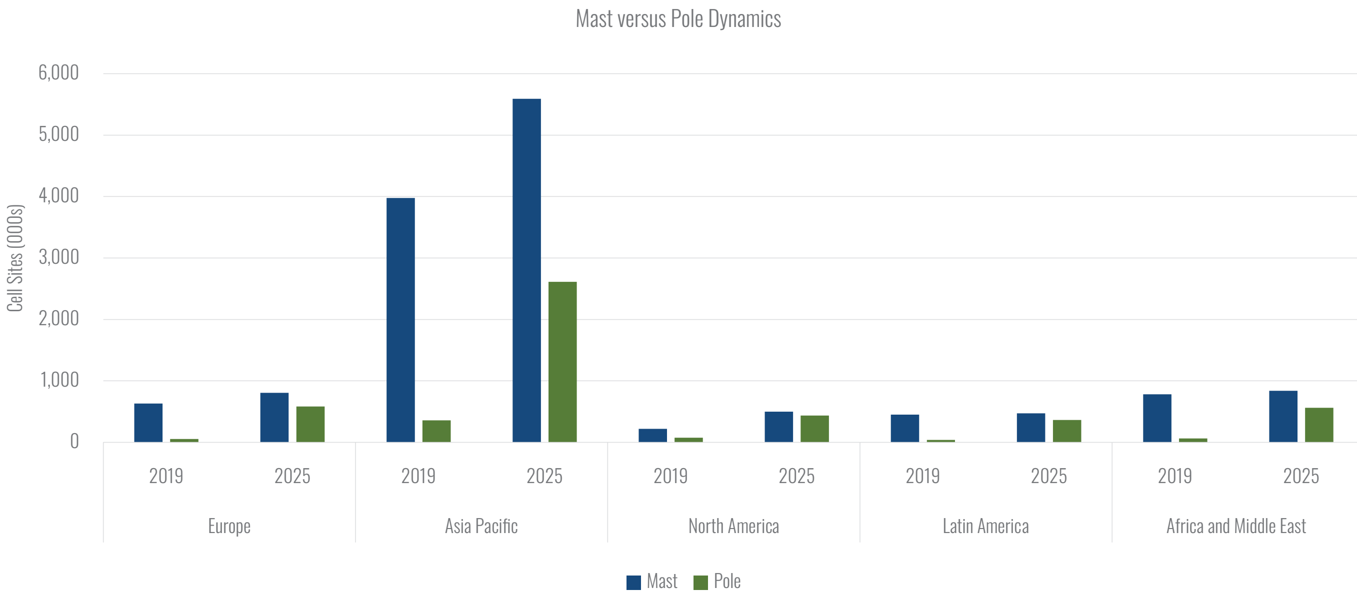
Pole Site

Small cells are being mainly deployed in highly densified areas with high data demand to increase the existing capacity delivered by the macrocell, and to provide coverage in black spots. In the global market, the installation of 3G/4G small cells is on a limited scale, mainly being deployed in countries like China, Thailand, etc. The small installation scale can be associated with difficulties that include site acquisition, power supply availability, existing planning regulations, and the lead time for delivering backhaul services. 5G small cells, however, are expected to be deployed in a much larger scale during the next 5 years. Although the speed of deployment can still be negatively impacted due to the reasons mentioned earlier.

The strategy adopted by MNOs for deploying 5G small cells might vary depending on the spectrum assets available. In the sub-6 Gigahertz (GHz) band, MNOs will favor deploying 5G in the macro layer for the next 3 years as a first phase of deployment, while during the second phase, MNOs will focus on deploying 5G small cells to achieve a ubiquitous and ultimate experience. By contrast, for MNOs with access to mmWave spectrum, deploying 5G in the macro and small cell layers will be equally important for delivering ubiquitous coverage and capacity over the 5G network.

Chart 4 shows that the use of pole sites for small cell deployments will grow on average approximately 3X to 4X across all regions. This behavior can be associated with the expected small cell densification in deploying 5G and the high potential for multi-operator pole site deployments.

Chart 4: Mast versus Pole Dynamics
World Markets, Forecasts: 2019 versus 2025
(Source: ABI Research)



The current trend in deploying small cells is to install one small cell per MNO per technology (3G/4G and 5G). This tendency stresses the structural capabilities, as well as the available power and backhaul delivered to the assets. In terms of backhaul solutions, many options are being considered, including fiber, copper, Non-Line-of-Sight (NLoS) sub-6 GHz, Line-of-Sight (LoS) 6 GHz-38 GHz, E-band, Wi-Fi, and in-band LTE.

Micro Cell Solutions

Microcell solutions are deployed in highly densified areas targeting both outdoor and indoor users. There are two main deployments of microcell solutions known as building facade and streetlamp microcells. The building facade deployment consists of the installation of external wall-mounted antennas, along with a telco cabinet to house backhaul equipment, power supply, and base station equipment. The cabinet can be installed indoors or outdoors depending on the available space within the premises. The second scenario consists of a base station, radio unit, and antenna contained in the same physical module. This type of microcell solution typically delivers a transmission power of 5 Watts (W).

INDOOR COVERAGE

Deploying 5G indoors has targeted high-density venues, such as stadiums, music venues, transportation hubs, railway stations, and airports, to ensure quality user experience, with MNOs starting to transition from traditional Distributed Antenna Systems (DASs) to digital Distributed Radio Systems (DRSs). This trend is mainly associated with two main factors: 1) the premium features that a DRS can offer compared to traditional DAS solutions, and 2) the challenges that a traditional DAS faces with upgrading to 5G to incorporate new frequency bands (typically C-band and mmWave) and increasing overall system capacity.

DRSs offer a more simplified architecture compared to traditional DAS solutions, which encompass a baseband unit, radio controller, and remote radio units or head-ends. The baseband unit is linked to the radio controller through fiber and the head-ends are connected to the controller through CAT6 cable or fiber depending on the vendor and the total length between the radio unit and the controller. DRSs can support the frequency bands in which 5G typically operates (C-band and mmWave), as well as distributed MIMO capabilities, cell splitting, joint scheduling, and virtualized Operations and Maintenance (O&M). A DRS can deliver 4x4 MIMO in a single headend through a single cable compared to a traditional DAS that will require 4X coaxial feeder cable, 4X passive components, additional active equipment, major reconstructive work, and a detailed analysis of the link budgets for correct balancing between the main and MIMO branches. Therefore, DRSs have significant advantages over traditional DASs and offer a cost-effective transition toward 5G for MNOs and wireless infrastructure providers.

KEY TAKE-AWAYS

- The imminent deployment of 5G stresses the need for physical site densification, and a more simplified site acquisition process to cope with the increasing service requirements.
- Rooftop deployments clearly make up a significant proportion of the mobile telcos' installed base of cell sites, which results in challenges regarding space, load, and high OPEX for the deployment of 5G. Thus, in order to reduce these cell site constrains, MNOs are likely to transition from indoor equipment rooms to full outdoor equipment installations.
- To date, the deployment of small cells in urban areas has been predominantly driven to address congestion issues at the macrocell layer. This trend is expected to change as small cells are going to be largely deployed to provide ubiquitous coverage and capacity for the higher spectrum bands (mmWave).
- For the delivery of in-building wireless, MNOs will continue to transition to digital DRSs to address coverage and capacity demands for both the consumer and enterprise markets. DRSs offer premium features and provide MNOs a cost-effective transition toward 5G.

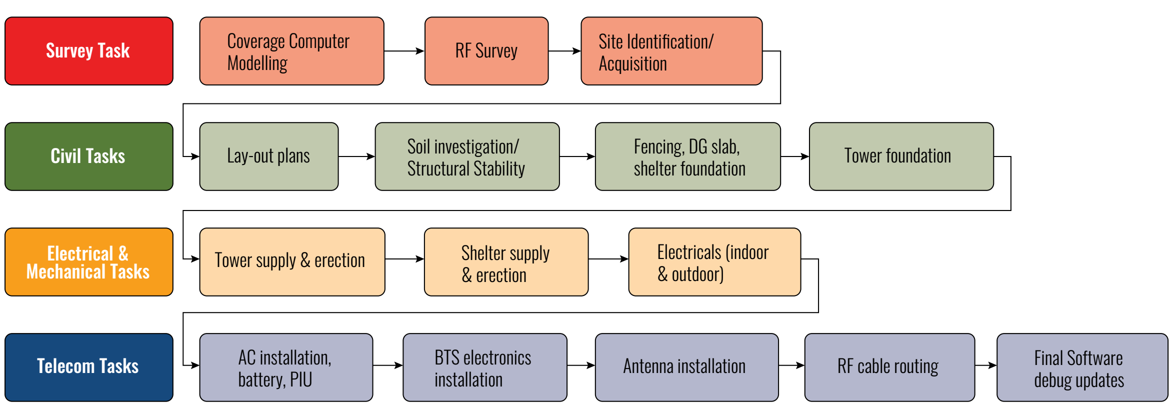
CELL SITE ACQUISITION CONSIDERATIONS

LOCAL AND NATIONAL GOVERNMENTS

In this section, ABI Research examines the generic government approval process regarding the deployment of cell sites for 5G. Regulators play an important role in creating the appropriate testbeds and environments that will drive the next stage of economic development and this starts with the rollout of 5G cell sites.

Figure 1: Cell Site Deployment Tasks

(Source: ABI Research)



Operators face opportunity cost, revenue loss, and churn rate as they battle to put out coverage for the community, so the time-to-market is critical. Civil tasks like simplifying layout plans and the government approval process can improve the economic surplus.

GOVERNMENT APPROVAL PROCESS

Operators typically will be required to sign a master lease agreement and submit a site permit application to the local government. Cell site zoning requirements vary significantly from country to country, as well as from municipality to municipality. There is a strong desire in the industry to simplify cell site zoning procedures, as they are often tortuous and complex.

KEY RESTRICTIONS & HURDLES

Operators need to know some factors regarding the types of wireless facilities permitted and zoning requirements when seeking to deploy 5G. Local governments also need to understand the differences in 5G cell site deployments. Crown Castle, a telecommunications infrastructure provider, claims that small cell deployments typically take about 18 to 24 months.

The cell site permit application process is one common challenge. The process for previous generation networks is ill-fitted for applying to 5G, as the types and the number of deployments for 5G are expected to include more variety and greater numbers. Previous generations needed a big tower, but 5G requires only a pole and smaller infrastructure (*e.g.*, a bus stop or lamppost).

While safety and heritage are key considerations for local governments, some practices should be avoided. These include having extensive and high fees for attachment and requiring operators to pay for the maintenance of public infrastructures. Telecommunications infrastructure plays a key role in the digital society and economy, so it is important for local governments to collaborate with operators on deployments.

Frameworks should be updated to better tackle small and macrocell site deployments. A set of criteria and guidelines established by local authorities, or a national authority, should communicate the requirements to operators in clear and precise language. Regulations and frameworks should include a clause setting the rules and timelines for all parties to follow, preventing unnecessary delays. The frameworks should also address fees payable by operators for new cell sites or renewal of cell sites.

Allocating enough space for infrastructure will provide operators with a better focus on value-driven activities and investments in equipment. Streamlining the permitting application will benefit local government in assessing and regulating cell site deployments without delays. Bundling multiple permits into a single application can streamline the process, reducing the time spent by local government officials.

In addition, the proximity and number of cell sites to be deployed exposes the community to something new and unknown, with resistance expected. A local government plays the important role of balancing the interests of different parties and assessing what would best benefit their local community.

CASE EXAMPLES

Simplifying Administrative Procedure

In 2020, the European Union adopted the Implementing Regulation on Small-Area Wireless Access Points (SAWAPs) that will accelerate 5G network installations. This is achieved by simplifying the deployment of small cell antennas that provide the last mile connection for 5G networks. One key focus is that small cells are exempted from having to apply for planning permits, which is expected to speed up deployments. For any SAWAP, the maximum volume allowed is set at 30 liters should it be exempted from planning permits.

Setting Regulations and Frameworks

The Infocomm Media Development Authority (IMDA) of Singapore instituted the Code of Practice for Info-Communication Facilities in Building (COPIF). The IMDA requires developers or owners to offer a specified amount of space for mobile deployments, without charge. To facilitate the deployment of 5G small cells, the IMDA has set up a working group with other relevant public agencies and MNOs to set the space and facilities requirements for 5G deployments.

LANDLORDS

When a cell site is to be deployed, it needs more than just an application and approval from the regulators. The optimal position and location where a cell site could belong to private property owners concerns landlords. Here we shall refer to landlords as private property owners in residential and non-residential areas. While there are differences in considerations for landlords in residential and non-residential areas, there are also key similarities (*e.g.*, the valuation of the land and property after the deployment).

KEY REQUIREMENTS

One of the key requirements is determining how and what the valuation for rent is between the landlord and operator. In some cases, the rental fee agreed upon between parties tends to vary on a case-by-case basis and negotiations could take months to reach an agreement; one small cell site deployment takes about 18 to 24 months according to some operators. Valuation on the property is typically based on multiple factors, including topography of the proposed cell site, complexity of construction costs, and proximity to the center of the search ring. As cell sites are perceived to be a negative factor for property valuation, landlords are unlikely to want a cell site near their property.

In the multi-operator's case, landlords might seek to gain a certain percentage from sublease agreements. Operator Optus cited concerns that private property owners see small cells deployments as a potential revenue source. While compensation for the use of private property should be made, excessive rent-seeking behavior of private property owners can delay the construction of necessary infrastructure and impede economic development.

CASE EXAMPLES

Setting Regulations and Frameworks

The introduction and amendment of the Electronic Communication Code in the United Kingdom addresses the challenges and issues between telecommunication operators and landowners. The updated code spells out what an operator can and cannot do when deploying on private lands. The valuation method for rent payable was also addressed in order to create a standardized and fair guideline on the amount payable for a deployment.

In terms of compensation, the landlord countered with a £13,500 (US$17,825) annual fee in contrast to the operator's submission of a £2,551 (US$3,368) annual fee. The Upper Tribunal ruled on the "no-network" basis for the valuation, thus adopting the value derived by the operator.

RECOMMENDATIONS

The need for a framework and/or code to guide the negotiation between parties is necessary. It helps establish the foundation on which different interests can make their respective requests. Rental fees payable by operators should not be excessive in value.

The number of cell sites required for a 5G deployment is vastly different from a single tower providing coverage. The sharing infrastructure model between operators is one of the ways to cope with the expenditure challenge of 5G. Both landlords and public infrastructure owners should understand the challenges of 5G cell site deployments, while deriving a fair amount of rent.

Operators and other companies (*e.g.*, e-payment solution providers, mobile device vendors) that can add value for the property owner should collaborate. The key objective is to increase the incentive for property owners to accept cell site deployments. For example, the property owner could obtain a higher margin from sales of a service package from operators as an incentive.

KEY TAKE-AWAYS

- Frameworks and regulations should be made to help guide discussions and achieve a consensus between different parties. With 5G, the local governments have an even more active role to play as public infrastructure (*e.g.*, streetlamps) is required for cell site deployments. Local governments should help tackle excessive rent-seeking behavior by private property owners, which undermines operators and negatively impacts the economy and economic growth.
- Operators need to be involved in governmental processes to harmonize the deployment of mobile network infrastructure. Flexible legislation with clear and precise guidelines can be designed that ultimately results in access to the infrastructure with telco apparatuses that are available in the market (*e.g.*, IMDA's case). Operators should seek new forms of strategic alliances and obtain new bargaining chips and incentives to offer economically rational proposals to property owners.

5G CELL-SITE UPGRADE AND DEPLOYMENT SOLUTIONS

Apart from the regulatory environment, operators need to resolve some technical challenges of cell site. A cell sites is made up of multiple components and a few of them, notably antenna, backhaul, and energy have seen innovations and upgrades occurring.

ANTENNAS

The challenge for operators is to deploy newly acquired spectrum without increasing the footprint at existing sites or creating new sites. As operators tackle the issue of deploying their newly acquired and existing spectrum, they also need to ensure that the Quality of Service (QoS) is maintained or improved in the process of adding spectrum.

CHALLENGES

Limited site space. A key challenge for operators is to maintain their current footprint on existing sites while deploying new spectrum. In some cell sites, operators face the challenge of insufficient space at existing sites. Antennas are deployed on single or double poles, which have a physical limit to the amount of space available. The addition of poles takes a long period for approval, estimated to be about 3 to 12 months and it entails civil work and cost. Not all cell sites can be expanded with additional poles to accommodate the additional equipment that comes with a 5G deployment. This greatly limits operators in using existing cell sites for 5G deployments. Reconstructing existing sites to expand space capacity also entails additional costs and time, further undermining operators.

Insufficient load bearing capacity or wind resistance. Each cell site has a limited load bearing and wind resistance capacity. When additional antennas are deployed on a cell site, the total weight and amount of wind load are expected to increase. Operators can reinforce a cell site to overcome this challenge, but the additional cost will have to be assessed. By one estimate, the construction cost for tower reinforcement could be up to US$10,000 per site. Mounting more antennas increases the leasing costs incurred.

Poor mounting location for M-MIMO. The location on the pole where mMIMO is mounted will impact coverage and performance. mMIMO mounted higher on the pole will provide better coverage for the sector. However, existing passive antennas occupy the upper sections of poles, which is the optimal location. Shifting the passive antennas will affect the performance of the existing network (3G/4G), resulting in a need for reconfiguration. Having mMIMO placed below the existing passive antennas reduces 5G coverage and is a sub-optimal deployment.

To address these challenges, there is a need for antenna technology and solutions to address the challenges of deploying more bands without increasing the footprint, all while ensuring the performance and coverage of the network remains top-notch. Solutions need to also provide operators with flexibility in deploying 5G networks.

SOLUTIONS

To tackle the challenges of upgrading existing sites to support 5G, operators could switch out the current antennas with one new antenna that is able to cover multiple frequency bands. This would help operators release existing site space used by existing antennas, so they can deploy new 5G equipment, while still keeping the current footprint on the cell site. Multiband antennas have been widely used in the global market and will play an increasingly important role for operators as they move toward 5G cell site deployments, while providing a Multiple Radio Access Technology (multi-RAT) network.

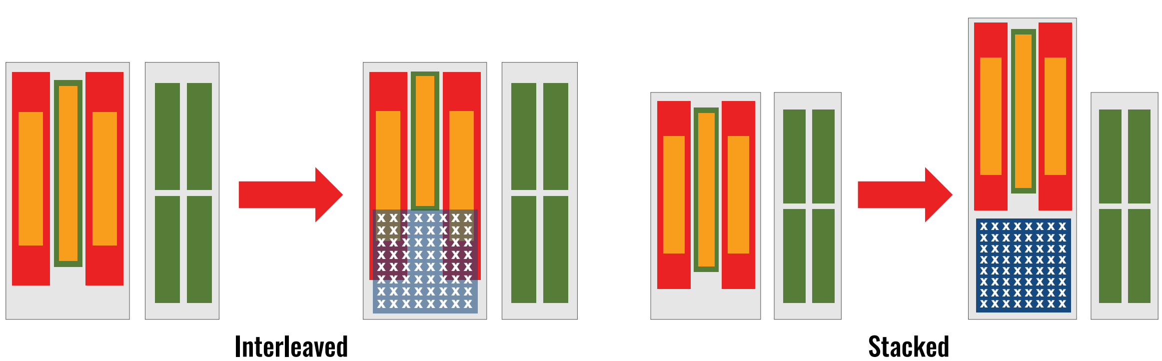
Each cell site has a load bearing capacity and physical space limitation, so the size and weight of any antenna to be deployed must be taken into consideration. A multiband antenna deployed to consolidate the sub-3 GHz bands with a significantly increased weight or size is suboptimal for operators. The best outcome would be consolidating legacy bands, while maintaining the weight and also the size of the antenna. This would also reduce the risk of increasing wind load placed on the antenna.

Some innovative antenna platforms in the industry use unique technologies to control the size, weight, and wind load of multi-band antennas. For example, Huawei's London antenna platform at only 1.5 meters was created to allow a 5G deployment without needing additional antenna space. Another example is Huawei's Munich Pro platform, which supports a maximum of 15 frequency bands and adapts Signal Direct Injection Feeding (SDIF) technology, making it an effective approach to integrating antenna components and improving the radiation efficiency of antennas. The reduction in weight also reduces the need for equipment (*e.g.*, cranes) during installation, thereby lowering the cost of deployment. Another solution is the Kathrein Mobile Communication's 378 antenna platform, with a width of only 378 millimeters (mm). The reduced form-factor has a reduced footprint and is equipped with vortex generators, which reduces frontal wind load.

Operators should also be future proofing their cell sites. This can be achieved through an Active Antenna System (AAS), which provides the flexibility of upgrading the cell site to cater to 5G, even if it is currently only used for 4G. An AAS typically ranges from 2 Meters (m) to 3 m depending on the configuration (interleaved or stacked). When considering the challenges faced by operators mentioned above, it is necessary that AAS deployments also address weight and size accordingly.

Figure 2: Interleaved Configuration versus Stacked Configuration for Active Antenna Systems

(Source: ABI Research)



While both configurations help with future-proofing cell sites for active antenna deployments, which are key for 5G, there is a difference in the outcome. Weight and size are important considerations for deployments. The optimal configuration is the interleaved configuration where the active arrays are superimposed onto the passive low-frequency (in red) arrays, maintaining the size of the antenna deployed. The stacked configuration results in an increase in the size of the solution and subjects the antenna to greater wind loads. An optimal solution must resolve the multiple challenges of size, weight, and performance of 5G deployments.

One key example is the Huawei BladeAAU. This solution integrates the active and passive components—the 5G mMIMO with legacy passive antenna modules—while maintaining the total height at 2 m in length. This is achieved by adopting the interleaved design as shown above. Using the interleaved design greatly simplifies the physical antenna and uses site resources more efficiently. In addition, it helps operators reduce the high operating costs at the sites. The Huawei BladeAAU could be used where site space is extremely limited (*e.g.*, one pole per sector), while ensuring the optimal deployment location of 5G.

CASE-EXAMPLES

Active Antenna Systems

Sunrise, a Swiss operator, implemented its 5G network with the use of an AAS. Sunrise used Huawei's BladeAAU between active and passive antennas to provide for the coverage. Using the BladeAAU shortened the overall 5G site deployment time significantly, as it cuts the time for new or additional poles, or the reconstruction of existing sites.

ENERGY

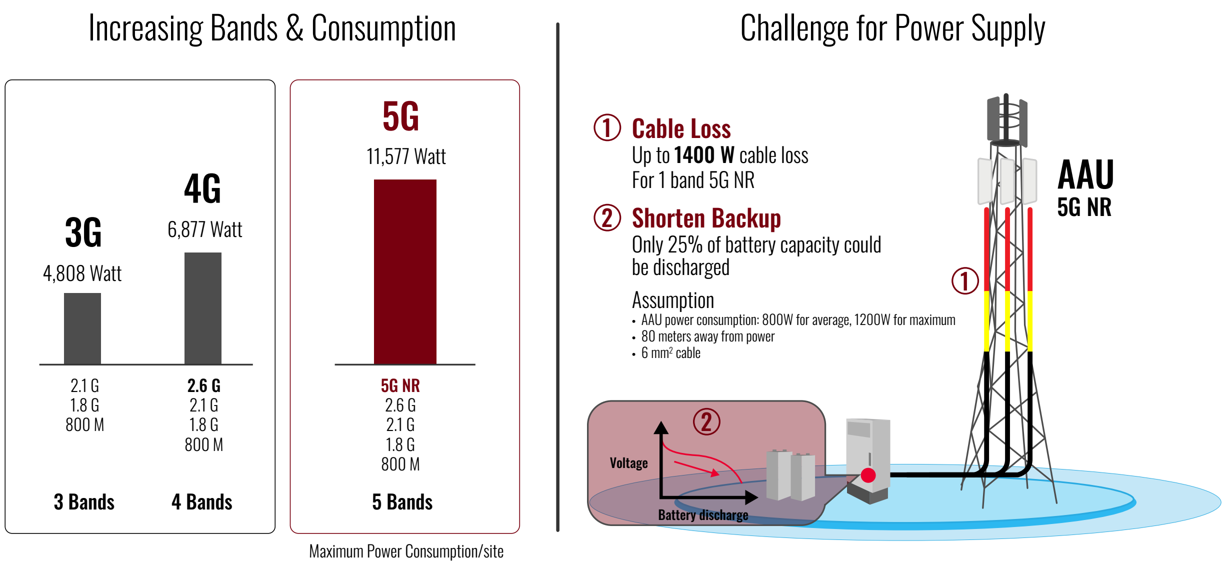
When deploying a cell site, the power requirement can typically be categorized as: 1) static power consumption, which is associated with the support system of a base station, and 2) dynamic power consumption, which is associated with the data traffic load. For a cell site, the amount of energy consumption varies depending on the amount of equipment and the number of frequency bands supported. Optimizing energy consumption can help operators lower their OPEX and achieve environmental goals.

CHALLENGES

Insufficient DC power *capacity*. Energy consumption is expected to increase with 5G deployments. New frequency bands and an increased number of equipment contribute to the this. Research on developed markets indicates that the maximum power consumption of a typical site supporting five bands could exceed 10 Kilowatts (kW). However, the reality is that about 30% of macrocell sites do not have a power supply that could support such power requirements. The common solution for energy expansion is adding more rectifiers or more energy cabinets. However, the equipment room or cabinet do not always have sufficient space for additional equipment. To cater to the increasing demand for energy, operators need to either find solutions that improve the existing equipment's efficiency or construct new cabinets at sites. However, newly constructed cabinets also entail increased civil work and rental costs for operators.

Figure 3: Increased Energy Requirements with More RF Bands

(Source: ABI Research)



Grid reconstruction. Grid power for the existing sites may be insufficient, especially due to the increase in power consumption with a 5G deployment. Such sites need grid modernization, which can be expensive and can greatly slow down the pace of a 5G deployment. Due to the process and construction requirements, the time to modernize the grid could be up to a year for each site.

Insufficient power backup. Operators need to meet the strict five nines or high availability of services. Ensuring business continuity is crucial for any operator. In times of prolonged bad weather or a power outage, grid and solar energy might not be available to power the cell site. Energy storage systems with lead-acid or lithium-ion batteries, for example, are required to mitigate the risk of a power outage. Most existing networks are still using lead-acid batteries, while the low-energy density, heavy weight, and big volume of a lead-acid battery make it difficult to do an expansion when deploying 5G.

High electricity cost. Another key challenge for operators is how to optimize energy efficiency, translating into good investments by operators. Relying solely on the electric grid could result in high energy expenditure, and the need to consider multiple energy resources. Traffic usage is also not constant throughout the day and varies depending on the location (*e.g.*, city centers versus suburbs). How operators can manage the energy system intelligently and efficiently to reduce unnecessary waste becomes a core consideration.

Given the rapid development of 5G technology and an increasing host of service applications, computing is getting closer to users, with communication technologies and information technologies evolving toward converged Information and Communications Technology (ICT) architecture at an ever-faster pace. The increasing applications and computing required at the edge means that the power supply demand is expected to increase. Therefore, it is necessary to consider the amount of Alternating Current (AC)/Direct Current (DC) power supply needed at the cell site, as well as the number of equipment rooms that are required.

SOLUTIONS

To address the challenge of limited space and high rental costs with expanding energy system capacity, cell sites will require simplification of the energy system. Simplification will not only help effectively manage the equipment, but also reduce the Capital Expenditure (CAPEX) and OPEX associated with the cell sites. Enhancing the density of the power and energy storage system and consolidating the system in one closure (*e.g*., one site, one cabinet concept) is one effective method.

For example, the 5G power solution provides higher power density (36 kW@5U) by adopting a modular approach to allow operators to tackle varying needs for different cell sites. It also reduces the need for multiple cabinets for 5G deployment, as it supports multiple voltage output standards (both DC12 ~ 36 Volt (V) and AC 220 V) for ICT convergence scenarios. Another solution, the Blade Power, also support high density (6 kW@15L power), enabling "one site, one blade, which can be deployed quickly without requiring a crane or heavy equipment. It also supports natural cooling with cutting-edge bionic cooling tooth root technology, which can improve cooling efficiency by 25%. Alternatively, an operator could change the way cooling is done for a cell site to reduce the amount of energy expenditure.

Alternative energy sources, such as solar, can help operators tackle the increase in energy use expected with 5G and acts as a backup source in case of a power outage. Alternative sources also allow operators to have the flexibility in planning energy use, instead of relying on a single source. The cost of energy is not constant between sources (*e.g*., solar versus grid), therefore, operators with alternatives have a flexibility in managing their energy expenditure.

Traditionally, lead-acid batteries have been primarily used for the energy storage system. However, with the improvement in Lithium-ion (Li-ion) battery performance (*e.g*., in lifespan, weight, and size), it has increasingly become the choice for energy storage. Intelligent Li-ion batteries (*e.g*., Huawei's 5G Power CloudLi) could be used as alternative during high electricity tariff periods. Depending on the type of tariff structure (tiered or peak/off-peak), a Li-on battery can play a role in optimizing the cost of energy incurred by operators. Some cell sites face the challenge of having sufficient grid power supplied as 5G draws more power than previous network generations. It is essential for the energy storage system to supplement the grid in order to power the equipment. This will help operators manage their grid electricity expenditure and avoid upgrade costs (*e.g*., for wires and other components) at the cell site for more power.

Management software also plays a key role in driving energy efficiency. Management software (*e.g*., Huawei PowerStar and NetEco) can predict and optimize the use of energy for the cell site based on data collected from the power system and battery unit. The existing energy system and equipment on the cell site need to be transformed into smart grids. Smart grids will allow operators to access real-time information on its operation. This could help operators optimize energy efficiency and achieve better and more cost-effective energy OPEX.

CASE-EXAMPLES

Energy Storage Solution and Management Software

Portuguese operator Altice Portugal faced the challenge of optimizing its OPEX, while evolving toward 5G. Portugal has one of Europe's most expensive electricity tariffs, even after price reductions. To cope with and optimize its energy expenditure, Altice Portugal implemented Huawei 5G Power CloudLi, a digital and intelligent Li-ion battery to play an active role in optimizing the energy system at the cell site. A battery management system also allowed the operator to introduce intelligent features, such as a charging and discharging schedule based on electricity tariff rates. Altice Portugal saved up to 9% on electricity expenditure for its cell sites, while managing its 5G deployment. Other operators, such as TIM Brazil, have also used the 5G Power CloudLi to reduce their OPEX and improve energy efficiency.

Crnogorski Telekom chose the Li-on battery solution to replace its existing lead-acid batteries as the source of backup power for its cell sites. The Li-on batteries were provided by Panasonic and managed by Ericsson. To optimize the energy usage, Crnogorski Telekom adopted the Energy Infrastructure Management. Energy Infrastructure Management, a collaboration between Ericsson and Panasonic, provides a means to measure, monitor, and maintain energy. The solution is said to help the operator reduce the cost of energy equipment ownership by up to 40%.

Management Software

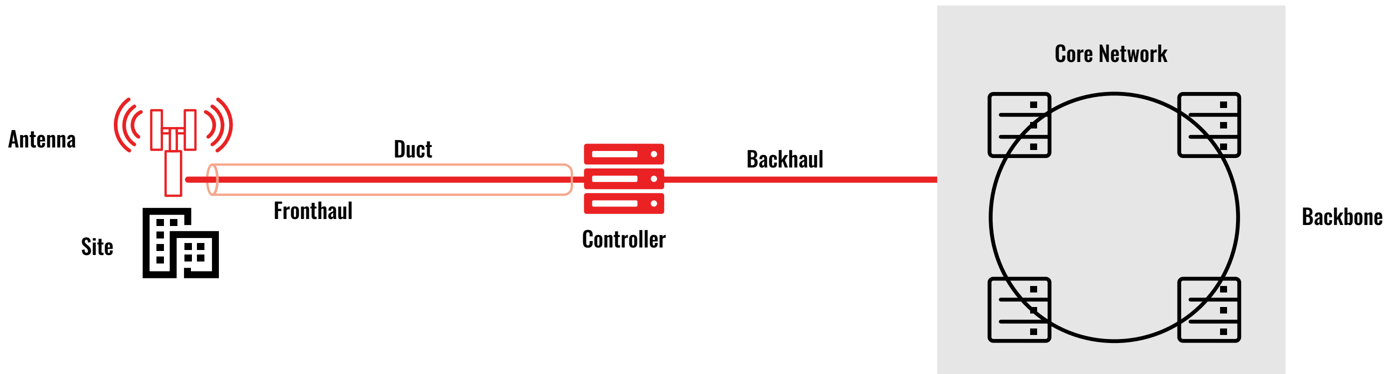
MTN South Africa has achieved better energy efficiency by using Huawei's PowerStar, which is a multi-band and multi-RAT (i.e., from 2G to 5G) software solution that monitors data from the network via Artificial Intelligence (AI). The software then uses the information to predict the network power requirements and achieve an ideal balance of power generation and power consumption ratios.

During the trial phase, the solution increased the energy saving rate from 3.6% to 11.6%, while maintaining the performance at a single site. PowerStar can enhance cellular network energy efficiency and network adaptability to adjust to different data traffic patterns. Huawei claimed that PowerStar reduces power consumption by 15% for wireless networks. Aside from Africa, the PowerStar solution has also been deployed in China and Ukraine and at more than 100,000 sites.

BACKHAUL SOLUTIONS ADOPTED

Backhaul refers to the portion of the network that links the core network with the radio access network. For operators, backhaul can be provided via fixed-line (*e.g*. using fiber) or wireless solutions (*e.g*. using microwave frequency band). With increasing data traffic, operators have to seek out solutions that optimize spectral efficiency and new frequency bands for backhaul. "Fronthaul" refers to the portion of the network between baseband controllers and the remote radio heads installed at cell sites. Figure 4 depicts the location where backhaul and fronthaul are located in the network.

Figure 4: Role of Fronthaul and Backhaul in a Network
(Source: GSMA)



CHALLENGES

The increasing worldwide data traffic, which is estimated to surpass 2,708 exabytes on an annual basis in 2025, will require operators to find solutions (*e.g.*, fixed or wireless) to meet demand. Fiber presents itself as the best choice for backhaul, but operators need to address the cost and logistics of deploying fiber. Wireless backhaul provides operators with a more cost-effective option for mobile backhaul compared to fiber. A deployment using wireless backhaul could also be done in matters of days and could support distances up to several km.

Insufficient space and high cost for expansion. The arrival of 5G means that the transmission bandwidth required for a single site could reach up to 10 Gbps. The existing solutions for microwave transmission will not be enough, typically a microwave outdoor unit supports hundreds of Megabits per Second (Mbps) to 1 Gbps, to fulfill the 5G bandwidth requirement. Therefore, multiple outdoor units need to be deployed at the cell site, adding to the rental and engineering costs of deployment (*e.g.*, site visit, installation, etc.). This will also pose a challenge to the tower space and load bearing capacity with the increased number of outdoor units deployed. In some cases, one frequency band may not be enough to cover the capacity requirement. Therefore, additional frequency bands will need to be deployed. This also results in additional antennas mounted on the tower, which contributes to increasing costs and physical limitations of the deployment.

Limited coverage distance for E-band. Due to limited channel bandwidth and limited resources of traditional frequency band (6 GHz-42 GHz), 5G has prompted regulators to allow the usage of spectrum in the higher mmWave bands, such as the unlicensed V-band (57 GHz-71 GHz) and the E-band (71 GHZ-86 GHz). These bands are great at handling the increased capacity and relatively more cost effective as they are unlicensed or lightly licensed. For shorter distance links (*e.g.*, small cell sites), the E-band is a popular choice, as it provides more bandwidth. It is projected that backhaul links supporting these solutions will account for around 65% of overall links from 2021 to 2027. However, due to the characteristics of the E-band, it faces the challenge of rain attenuation and shorter propagation distance. Rain attenuation happens when the frequency signal is lost during heavy rains, thereby limiting its coverage distance.

SOLUTIONS

Aside from the supply for the backhaul network, operators also require solutions that help better optimize the various assets they possess. The band and Carrier Aggregation (CA) allow an operator to construct higher capacity for point-to-point connections. For example, combining lower bands (*e.g*., 15 GHz, 18 GHz, or 23 GHz) with the E-band using dual band antennas would allow links to cover 7 km to 10 km with capacities that can exceed 10 Gbps. This also helps overcome the propagation challenge faced by the E-band and the capacity challenge faced by microwave. Solutions that can deploy additional frequencies, while maintaining the footprint of a cell site are essential for operators in 5G deployments.

LoS MIMO. Spectrum is limited and costly (i.e., licensed), so operators need to optimize spectral efficiency to maximize their utility from available spectrum. An LoS 2x2 Multi Input, Multi Output (MIMO) wireless link is made up of two transmitters and receivers connected to two antennas on each side. Capacity enhancements of LoS MIMO would equate to enhancing spectral efficiency, allowing more data to be transmitted over the same allocated frequency of the operator. However, cell sites often face the challenge of obstructions. This greatly limits the LoS backhaul solution over other NLoS backhaul solutions. Operators have to choose, based on the cell site's environment, the suitable solution to enable optimal backhaul performance.

Dual-band antenna and CA ODUs. The 5G microwave "1+2" architecture (one dual-band antenna plus two Radio Frequency (RF) units), pioneered by Huawei, allows operators to achieve up to 50% saving on tower space and engineering-related costs. This is achieved by eliminating the need for additional antennas that comes with deploying a new frequency band, thereby reducing costs. The architecture allows two different or similar RFs to be transmitted via a single antenna and can achieve at least 10 Gbps. Huawei's CA outdoor unit can aggregate four carriers into one hardware, achieving 4X capacity with 75% less hardware quantity compared with a traditional single carrier outdoor unit. The E-band, however, faces limits in the transmission distance, which means that backhaul done using the E-band is best suited for short distance links depending on the environment and equipment.

Intelligent beam tracking. To extend the usage and coverage of the E-band, solutions such as the Intelligent Beam Tracking (IBT) antenna from Huawei can be used. The antenna will enable beams to automatically maintain their orientation when detecting that signal towers shake or shift. IBT antenna allows large diameter antenna to be used for E-Band now without high cost for tower reinforcement. Large diameter antenna could increase transmission distance. Before it is difficult to use as greater tower stability is required due to the small beam angle of large diameter antenna. Compared with 0.3 m antenna, the 0.6 m antenna with IBT technology increases the coverage distance by up to 40%. These solutions help increase the coverage distance, while tackling the TCO challenge.

CASE-EXAMPLES

Zain, a Saudi Arab operator, implemented E-Band/SDB microwave solutions in their 5G deployment. For link distance below 3 Km, they used E-Band microwave, while for link distances between 3 Km to 7 Km, they choose Huawei's SDB (Super Dual Band) solutions, which is capable of supporting 20 Gbps/link. Over 2,000 E-band XPIC (Cross-polarization Interference Cancellation) backhaul links have been deployed.

Figure 5: Microwave Backhaul Solution

(Source: ABI Research)

INFRASTRUCTURE INNOVATIONS

In cell site deployments, the ease and time taken for one cell site to be up and running is of crucial importance for operators. Reducing the complexity and duration of deployments can help operators achieve greater value for their investments in deployments. This is especially crucial for 5G, with the number of cell sites expected to be greater than before. Cell sites could be located on top of roofs, along the streets, or hidden underground.

One key aspect for deployment is the ease of equipment installation. Equipment will be mounted onto infrastructure like utility poles, which have varying diameters, ranging from 8 inches to 27 inches. Poles with larger diameters require customized mounting kits, a greater number of field engineers, and a longer period to complete the installation. Below are some examples of bracket solutions.

Table 1: Cell Site Mounting Solutions

(Source: ABI Research)

VENDOR/SOLUTION	DEFINITION
Huawei/Chain Mounting Kit	Adapt to the varying diameters of different poles (140 ~ 400mm) or sites and support up to nine remote radio units using the same kit on the same layer. It also reduces the time to market from 8 weeks to 1 week.
Ericsson/Composite Brackets	Serving as a simple radio and outdoor baseband snap-fit mounting system. These brackets are rust-free, lightweight, and generate less waste during the manufacturing process.

NOVEL CELL SITE SOLUTIONS

SITE BEAUTIFICATION/CAMOUFLAGE STATIONS

Deploying cell sites is often faced with challenges from local administrations' zoning requirements for any RF equipment to blend into its surrounding or resistance due to aesthetic reasons from the community. To address these challenges, site beautification and camouflaged cell sites have started to be seen more commonly. A key part of concealment is to ensure performance, making the material or product RF transparent.

Figure 6: Antenna without Reflective Film (left) versus Antenna Applied with Reflective Film (right)

(Sources: Public Domain Image and Obscure Tech)

Obscure Tech's reflective film technology can be applied to all telecommunications infrastructures and eliminates expensive structures or faux facades. The company collaborates with 3M for the film used in its solutions. Using a high-quality photo image or color matching concealment film, the equipment can be made to appear hidden or to reflect its surroundings.

SMART STREET CELL SITE SOLUTIONS

One of the key public infrastructures for deploying 5G cell sites for small cell densification is the lamp post. Lamp posts are located throughout cites and are better equipped with electricity than a utility pole. In addition, lamp posts are an essential part of a smart city project, making them a good fit for integrating and deploying small cells.

Figure 7: Smart Street Lighting (Daytime)

(Source: NEC)

The Tokyo Metropolitan Government rolled out a trial for smart street lighting equipped with a 5G antenna in the Nishi-Shinjuku area. Partnering with Sumitomo Corp and NEC, the local government plans to deploy 5G antennas across the entire metropolis. Smart street lighting can incorporate other features, such as sensors, Light-Emitting Diode (LED) signage, speakers, and intercoms to complement the connectivity and lighting functions.

Other vendors have also developed innovative products to tackle the challenge of cell site densification. Examples are listed in Table 2.

Table 2: Smart Street Cell Site Solutions
(Source: ABI Research)

VENDOR/SOLUTION	DEFINITION
Huawei/PoleStar	It integrates the 4G/5G base stations, transmission, and power system, providing additional services, such as smart lighting, smart monitoring, Internet of Things (IoT), smart environmental protection, and city information, on top of cellular connectivity. Providing additional services lowers the cost of deployment and drives the development of smart cities.
Nokia/Smart Pole	It integrates digital controlled LED lights, antennas, base stations, sensors, solutions for smart cities, and information screens. The solution will enable 5G digital services to monitor air quality and improve road safety and transport efficiency.

KEY TAKE-AWAYS

- In the 5G era, operators are faced with regulatory challenges to deployment, along with antenna, energy, backhaul capabilities, and infrastructure innovations, which are all part of the equation. Different deployment environments and scenarios (*e.g.*, urban, suburban) pose different challenges for operators.
- Antennas have to support both legacy and new frequency bands, while maintaining their footprint on site. Solutions like multiband antennas and interleaved mMIMO will help operators overcome the challenges to 5G deployments. Systems that help operators prepare for the future deployment of 5G capability and smooth out the transition are critical in lowering the cost of deployment.
- In terms of energy, operators need to adapt high-density energy systems to simplify site configuration and optimize site TCO when upgrading. Alternative energy sources, such as solar, provide a good complement for operators, while satisfying environmental sustainability goals. Operators need to also build in sensors and management software to make smart grids, allowing real-time monitoring and adjustment of energy usage. Energy storage systems (*e.g.*, with Li-ion batteries) have an important role to play in helping operators achieve better energy efficiency and manage costs.
- Backhaul needs to meet the increasing amounts of data traffic that will come with 5G applications. Microwave-based solutions have been widely used for backhauling; however, there are limitations to using it alone. The E-band has more bandwidth than microwave, but faces the challenge of coverage distance. Operators have to tap into technologies like band CA, LoS/NLoS, MIMO, or solutions like the IBT antennas to increase capacity and maximize spectrum efficiency.
- Solutions like the bracket kits from Huawei and Ericsson provide operators a level of flexibility in overcoming the varying environmental conditions where 5G deployments could take place. Finally, smart street cell sites (*e.g.*, in the form of street lamp) are key infrastructure options that will help operators with 5G deployments, especially with small cell densification.

FUTURE EVOLUTION OF CELL-SITES

Given the expected demand for higher data throughput and network availability, MNOs are adopting several strategies to enhance network performance, network availability, and, ultimately, user experience. Factors like spectrum availability, cell site densification, and technology innovation will help MNOs deliver world-class service to end users. Future-looking technological innovation in backhaul, antenna, power solutions, and cell site infrastructure will cooperate with the massive network densification and rapid adoption of cutting-edge applications enabled by 5G and future cellular technologies.

FUTURE OPERATOR REQUIREMENTS

In light of the accelerated deployments of 5G and the increasing number of applications that require reduced latency, transitioning from a centralized data center to distributed edge sites is becoming crucial for global and industrial digitalization. This trend implies new and innovative solutions that enable MNOs to easily deploy new cell sites. MNOs will be looking for site solutions with reduced CAPEX and OPEX, and enhanced O&M solutions that allow remote control and monitoring of the infrastructure. Furthermore, MNOs will require the following solutions:

1. New generation of communications equipment room that can support and deliver different power sources aiming for flexible and easy deployment of mobile network infrastructure in both rural and urban areas. The new generation of communications rooms should provide adequate environmental conditions for Information Technology (IT) devices to support edge computing and IoT applications.
2. Enhanced cell site security for new and existing sites. In the 5G era, the data will be processed and stored locally, demanding new and enhanced mechanisms that can protect the mobile network infrastructure and information from vandalism and thievery.
3. Flexible cellular infrastructure with reduced cost of deployment that enable MNOs to deploy cell sites in urban and rural areas improving the Average Revenue per User (ARPU).
4. Innovation in cellular equipment in terms of size, enclosure capabilities, aesthetics, and reduced power consumption.
    - Smaller-sized equipment (*e.g.*, baseband units, radios, and antennas) will reduce the footprint of the telco apparatus in a communications room. This will enable an easy upgrade at legacy cell sites to incorporate 5G, particularly at cell sites where there is reduced space for the new telco kit.
    - Outdoor-rated cellular equipment, such as batteries and baseband units, will reduce the requirements and capabilities of communications equipment rooms, such as space and air conditioning requirements.
    - Aesthetic and pleasant equipment that goes in line with local government regulators to lower the barrier of deployment of cell sites.
    - Equipment with reduced power consumption will enable MNOs to further generate some savings on electricity bills, as well as reduced power requirements from the grid or alternative renewable energy sources.

FUTURE EVOLUTION OF SUPPORTING TECHNOLOGIES

ANTENNAS

The design and development of antennas for 5G is facing several challenges due to the introduction of new spectrum and the requirements of higher MIMO capabilities. These challenges include antenna performance, reliability, aesthetics, lighter weight, and enhanced power consumption. Table 3 provides a description of the most future-looking antenna developments in the 5G era.

Table 3: Future-Looking Antenna Developments

(Source: ABI Research)

DEVELOPMENT	SCOPE	BENEFIT
See-through mMIMO Technology	Huawei's Massive MIMO and passive antennas could be installed and maintained separately. mMIMO components are arranged behind the passive antenna and, therefore, the mMIMO antenna needs to be directly connected to work on a fully standalone configuration. It can support flexible customization and only the passive components need to be modified without altering the solution.	This feature is needed to improve the flexibility of an active and passive antenna integrated solution, protecting a customer's investment.
Glass Antenna	The glass-embedded antenna adds cellular base stations to the windows in indoor locations to deliver indoor and outdoor coverage, as well as in vehicles and trains. The glass antenna can receive and transmit 5G radio waves in the 3 GHz and 4 GHz bands, with the latest trials carried out in the 28 GHz mmWave band. DOCOMO, AGC, and Ericsson will continue to work on the technological enhancements of this antenna technology to incorporate mMIMO capabilities.	By deploying the glass antenna behind the window to target outdoor areas, new antenna locations can be found that do not rely on street furniture, reducing the barriers of 4G/5G network densification due to its immediate camouflage with the window.
MQ4/MQ5 Cluster Connector	The MQ4 connector supports four RF ports and the MQ5 connector supports four RF ports and one calibration port. Huawei's solution can decrease the number of connectors required. Antennas can therefore be kept to a slim profile with more bands and easier to deploy with 4T4R and 8T8R. For example, by using MQ4 and MQ5 for the 2L4H+8SH@8T8R antenna, it only needs 16 connectors, decreasing the number of connectors by 46% as compared to the traditional 30 connectors. NGMN (Next Generation Mobile Networks) is set to recommend Type C (MQ4/MQ5) as cluster connector as the industry standard for early 5G deployment.	The solution is dynamically PIM tested with low-loss performance. It also enables easy installation and correct connection.
Interleaved Passive-Active Antenna (IPAA)	The IPAA is an antenna solution from a joint development between CommScope and Nokia, which encompasses base and top modules. The base module or multiband passive antenna enables operators to support low- and mid-frequency bands. The top module can support active mMIMO and an extension of the passive arrays for 5G in the 3.5 GHz band. Both the base and top modules are interconnected through the streamlined interface at the back of the antenna, minimizing transmission losses, while simplifying connectivity for faster installation. The IPAA modularity adds flexibility for field upgrades to incorporate 5G because the top module can be added without altering the passive components of the solution.	The solution enables MNOs to complete site upgrades without the need for additional space, increasing cell site capacity and setting the scene for a faster 5G rollout, while protecting the operator's investment.
M-LOC Cluster Connector	The M-LOC by CommScope is available with four or five ports. The mechanisms assure a secure connection, eliminating the risk of installation errors due to only one possible orientation. In the five-port variant, the fifth port can be used for signaling calibration. A patent-pending latching mechanism prevents accidental opening.	The solution is dynamically Passive Intermodulation (PIM) tested with low-loss performance capabilities that enable simplified and secure installation.

ENERGY

With the rapid development of 5G technology and an increasing host of services and applications at the edge, computing is getting closer to users, and communication and information technologies are evolving toward a converged ICT architecture at an ever-faster pace. The increasing number of applications and computing required at the edge means that the need for improved power supply is expected. Therefore, it is necessary to consider diversified energy solutions, such as AC/DC power supply at the cell site, as well as alternative energy solutions for small cell densification and the deployment of indoor wireless infrastructure.

Table 4: Future-Looking Energy Solutions

(Source: ABI Research)

DEVELOPMENT	SCOPE	BENEFIT
5G Energy MIMO (eMIMO) Power	The power solution from Huawei is capable of powering up base stations of legacy cellular technologies, 5G, edge computing, and IoT applications. This platform supports multi-output voltage, such as 12 VDC, 24 VDC, 48 VDC, and 57 VDC as well as 220 VAC for different systems, *e.g.*, cameras, sensors and IT devices. For the power input, the platform supports multiple sources of energy such as renewable solar energy, Diesel Generators (DGs), and power delivered from the grid.	The eMIMO platform can support the requirements of the undergoing digital transformation in the 5G era, where edge computing and IoT solutions can converge in the same cell site, thus connecting different equipment and multiple devices with different power modes, enabling digital applications that give relevant information to different industries.
Distributed Power Connectivity	The solution by CommScope uses Hybrid Fiber Cabling (HFC) to provide backhaul and power connectivity from a centralized location to a set of small cells deployed in a cluster. The central cabinet should, therefore, have access to power and the transport network. Furthermore, the cabinet will facilitate the deployment of battery backup in the centralized locations.	This technique reduces the footprint of equipment deployed at street level and enables small cells to have power redundancy. In addition, it allows the distribution of higher voltage over longer distances.
Digital Electricity	Digital electricity by VoltServer has safe power distribution. Provides indoor and outdoor radio locations with reliable centralized backup power, and centralized monitoring and control, while delivering power in the same pathway as fiber to the remote node.	Allows for rapid network deployment addressing the issues of lack of power in remote location for the deployment of DAS solutions, thus eliminating the need for delivery of a new power supply.

BACKHAUL SOLUTIONS

In order to cope with increased data traffic demands, innovative transmission technology will need to be available for the effective delivery of cellular services. Future-looking technologies, such as Integrated Access Backhaul (IAB), Free-Space Optical (FSO), and Low Earth Orbit (LEO) satellites like Starlink (SpaceX), are examples of these backhaul alternatives.

Integrated Access Backhaul

IAB was standardized by The 3rd Generation Partnership Project (3GPP) in Release 16 for 5G. With IAB, spectrum resources can be allocated to support both backhaul and access functionalities. In 5G New Radio (NR), this backhaul solution can be thought of as a feasible alternative due to two main reasons:

- The high bandwidth of the mmWave spectrum allows for allocation of resources for the delivery of backhaul without severely compromising the spectrum allocation for the radio access.
- Reduced risk of interreference between the access and backhaul due to the beamforming characteristics of 5G.

This approach will ultimately enable a faster densification of small cells, as not all units will require wired backhaul. Instead, a mesh backhaul network can be configured in which only one portion of the site has a dedicated fiber Point of Presence (POP) delivered to it. However, MNOs should make a tradeoff between the spectrum allocated to the backhaul provisioning and the cost savings on fiber. Less spectrum provided to the access network will ultimately result in less throughput and the potential to reach network congestion in very high densified areas. Technically, IAB can be deployed in any band allocated for 5G. However, it is envisioned that 26 GHz and 28 GHz will be the most prevalent for urban small cell deployments, while 3.5 GHz will be deployed for rural environments.

Free-Space Optics

FSO is an optical LoS communication technology that uses visible or infrared beams of light to provide high-capacity transmission for both fronthaul and backhaul. FSO uses unlicensed spectrum and can be deployed in hybrid configurations, along with the E-band. This hybrid combination can provide even higher data capacities in the wireless link. However, FSO has two main drawbacks, which have prevented it from becoming an option for fixed wireless backhaul:

- Environmental factors, such as clutter (*e.g*., trees) and weather conditions (*e.g*., rain and fog) can affect the system data rates.
- Short-range link distance.

Despite these limitations, FSO can become mainstream for backhaul delivery for 5G and future cellular technologies due to two main factors: 1) the expected short-range distance between small cells deployed in urban areas, mainly due to the high bands of spectrum (mmWave), and 2) areas/cities where there is limited or no presence of fiber and civil works to install fiber could increase the cost and complexity of small cell deployments.

Low Earth Orbit Satellite

Satellite backhaul can provide ubiquitous coverage, security, and availability, making it very suitable for cell sites operating in rural and remote hard-to-reach unconnected areas. In urban areas, satellite backhaul can work as backup to existing fiber, microwave, or mmWave links, or as a contingency for backhaul provisioning for temporal cell sites, such as at sporting events or festivals.

LEO satellites have an optimistic future due to their applicability in 5G scenarios that require high throughputs, high capacity, and low latency. LEO satellites are located at altitudes between 400 km and 1,500 km and can deliver high-capacity links of 1 Gbps to 5 Gbps with latencies of 20 ms to 32 ms.

Despite these advantages, LEO constellations are in development and have not been commercialized yet, as they have to overcome other issues before the technology can become commercially viable. The main issues can be described as follows:

- The installation of LEO satellites is costly due to reduced coverage area and reduced visibility on Earth. LEO satellites need to be deployed on a large-scale compared with Geostationary Earth Orbit (GEO) and Medium Earth Orbit (MEO) satellites. Similarly, terrestrial gateways need to be largely deployed to ensure the correct operability of the satellite constellation.
- The terrestrial infrastructure represents a cost increase in the overall operation. LEO satellite constellations are much more complex to operate, as the ground stations require expensive antennas for satellite tracking and complex systems to support multiple handovers between several satellites.
- The Return on Investment (ROI) in deploying LEO satellites has a large delay because a high percentage of the constellation needs to be operational before any service can be offered to end users.
- LEO satellites present a deficiency of adaptability because once a constellation is launched, it is not possible to perform changes in performance or the services without replacing the entire constellation.

In order to overcome these challenges, a cost reduction in terms of production, launch expenses, user equipment, and ground equipment is necessary to realize the benefits of deploying LEO satellites.

KEY TAKEAWAYS

- 5G network densification at street level is a key enabler of future cellular applications that require extreme small cell densification, thereby providing high reliable network coverage for applications like self-driving vehicles, platooning, and intelligent roads.
- The wireless satellite backhaul provisioning is a game changer in the telco industry. These backhaul solutions will enable reaching rural areas and ubiquitous wireless broadband connectivity in the future. However, these solutions still have to overcome a number of issues before the technology can become commercially viable.
- The accelerated industry digital transformation and the new distributed core architecture of 5G means that it is anticipated that new cell sites with edge computing and IoT solutions will be massively deployed. Therefore, communications rooms that are easily deployable and can provide power supply to different services are likely to be largely adopted by MNOs.
- IAB solutions will ease and accelerate the deployment of small cells in high-frequency bands. This backhaul provision will reduce the cost of deployments and provide an easy migration to fiber-based backhaul if needed.

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