COMMUNICATIONS NETWORKS WHITE PAPER

The 5G Power Architecture

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INTRODUCTION

Over the last couple decades, cellular networks and wireless technology freed us from the wireline phone and desktop computer, creating an access anywhere, anytime culture. Now, 5G is not only positioned to deliver greater bandwidth to our personal devices, but also deliver the low latency needed to achieve the promise of enhanced services such as interactive gaming, autonomous vehicles, remote surgery, and enhanced virtual and augmented reality. With more frequencies to transfer data, 5G is the enabler for Industry 4.0, providing the lowest possible wireless latency for critical data streams and increasing the number of connected devices to drive the Internet of Things (IoT). The result will be a connected world that affects everything from manufacturing and healthcare, to aerospace & defense, to agriculture and transportation. 5G will take the wireless transformation to a new plateau.

The construction of a 5G network build is a tremendous undertaking, affecting all aspects of the network. Like previous generations, upgrades are needed in macro cell sites and the mobile core. But to deliver universal high bandwidth, low latency service, 5G requires additional deployments in the form of edge computing and small cells by the thousands.

Powering the 5G network will require advances in power conversion and energy storage for powering outdoor small cells and devices at the top of the tower. The purpose of this paper is to introduce power requirements for each element of the 5G network. It provides an overview of the drivers for the requirements as well as the alternatives for solving the challenges. This paper will be followed by additional papers detailing the requirements and solutions for the various 5G network elements.

5G IS NOT ONLY POSITIONED TO DELIVER GREATER BANDWIDTH TO OUR PERSONAL DEVICES, BUT ALSO TO DELIVER THE LOW LATENCY NEEDED TO ACHIEVE THE PROMISE OF ENHANCED SERVICES

BACKGROUND

Accomplishing faster and ubiquitous wireless communications requires significant investments in the network. According to the 2020 global edition of the GSMA report, "Mobile Economy," 5G mobile operators are expected to invest $1.1 trillion worldwide between 2020 and 2025, roughly 80% of this in 5G networks[1]. While much of the investment is in spectrum, Radio Access Network (RAN) equipment, and Multi-Access Edge Computing (MEC), upgrades in infrastructure in the form of fronthaul, backhaul, concealment, and power will be needed as well.

Backhaul and fronthaul are well understood by the Mobile Network Operators (MNOs), who are keenly aware of the need for high bandwidth connections to link all the distributed elements in the network. Fiber is the preferred choice, though some operators have turned to the coaxial networks offered by Cable Multiple Systems Operators (MSO's). Microwave can also provide backhaul, but usage is declining. The medium must meet the performance requirements (e.g., bandwidth, latency, and jitter) and be available where and when needed.

Power and energy storage are known commodities in macro cells and the mobile core. Deployment issues such as capacity, physical space, environmental issues, and battery reserve time, are familiar to MNOs. However, 5G does have unique requirements. For distributed devices such

5G MOBILE OPERATORS ARE EXPECTED TO INVEST **$1.1 TRILLION WORLDWIDE** BETWEEN 2020 AND 2025, ROUGHLY 80% OF THIS IN 5G NETWORKS

1 https://www.gsma.com/newsroom/press-release/gsma-5g-moves-from-hype-to-reality-but-4g-still-king/#:~:text=The%20industry%20is%20investing%20heavily,will%20be%20on%205G%20networks.

POWER WILL CLEARLY BE A MAJOR FACTOR IN 5G DEPLOYMENT. THE INCREASED AMOUNT OF POWER NEEDED AT MACRO CELLS, THE ADVENT OF MOBILE EDGE COMPUTING, AND THE PROLIFERATION OF SMALL CELLS WILL ALL AFFECT REQUIREMENTS FOR POWER.

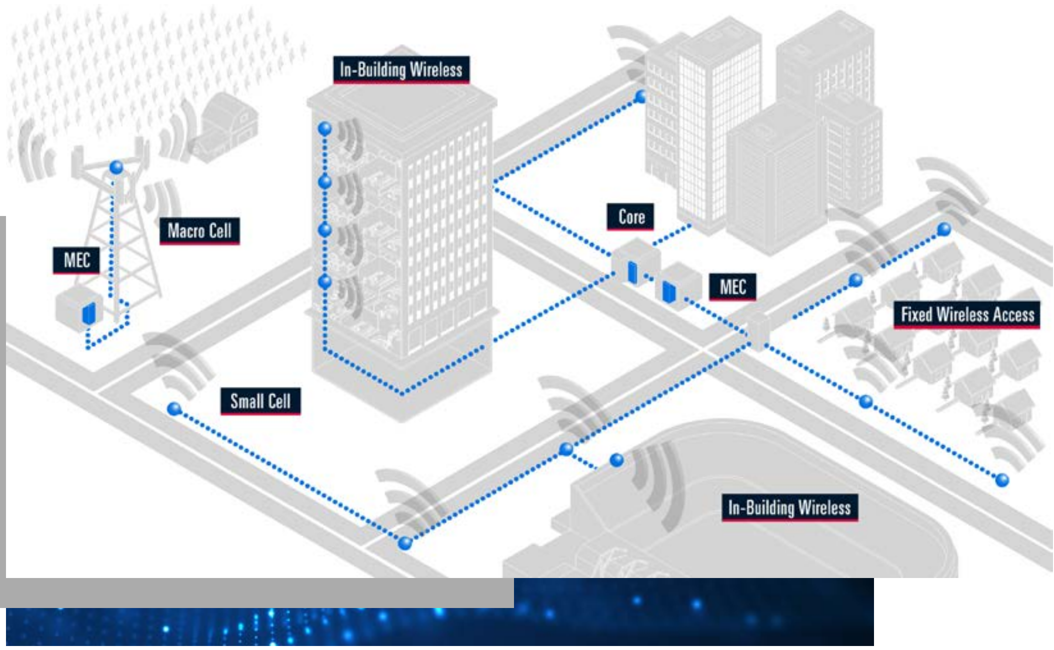
as outdoor or indoor small cells or Remote Radio Units (RRUs), power can either be a hurdle or enabler to deployment.

In distributed networks, there are fewer discussions about power, perhaps because it is assumed to be universally available in developed countries. In fact, in a survey conducted by the Small Cell Forum in 2017, power did not make the top ten hurdles to small cell deployment[2]. However, lessons learned during the deployment of 4G small cells point out the challenges power presents when building new sites.

In the 5G ecosystem, great strides have been made by the radio manufacturers to increase power efficiency of all radio and communication components. According to Nokia in a study conducted with Telefónica, 5G is up to 90% more energy efficient per data traffic capacity compared to legacy 4G networks[3]. However, as 5G networks handle many more data units simultaneously in each spectrum channel, the radio head and overall site power consumption is increased. In other words, while the amount of power required per byte of bandwidth has declined, the tremendous increase in transmitted data results in net growth in power consumption.

Powering considerations will clearly be a major factor for 5G deployment. The increased amount of power needed at macro cells, the advent of edge computing, and the proliferation of small cells will all affect powering requirements. Some changes will be additive, others transformative. The purpose of this paper is to provide an overview of the implications for power in 5G networks.

2 Small Cell Forum, Document 050.10.01, "Small cells market status report December 2017"
3 https://www.nokia.com/about-us/news/releases/2020/12/02/nokia-confirms-5g-as-90-percent-more-energy-efficient/



ELEMENTS OF THE 5G ECOSYSTEM

Creating a 5G-capable network requires more than upgrades to the RAN and mobile devices. In fact, it affects both wireline and wireless networks. Connecting small cells to the network will require an enormous increase in the number of fiber optic or coaxial connections to provide backhaul and fronthaul. Also, additional bandwidth capacity may be required at the core, meaning significant changes to wireline central offices and data centers. Although backhaul connections and bandwidth enhancements are intriguing, they are not covered in this paper. Instead, our focus is on the five key elements of the 5G ecosystem: mobile core, macro cells, small cells, edge computing, and private 5G networks.

The macro cell and small cells are the most visible elements. Edge computing is less obvious as it starts as a centralized function that will be moved closer to the end user as technology (and demand) permit. For private 5G networks, we look at office buildings, factories, arenas, and campuses. Our overview discussion for each of the five elements in this paper will be followed up by detailed papers on each network element.

5G Implementation Trends

The implementation of 5G requires changes in spectrum, radios, antennas, backhaul, and the architecture of the RAN itself. All these changes impact the requirements for power and battery backup. We address the impact for power and backup at the physical sites in subsequent sections of the paper. But before we cover those specific issues, we need to take a look at two elements in the RAN that are making 5G possible.

Spectrum: 5G is being deployed over three spectrum bands (see Table 1). Each band has its specific benefits and drawbacks. Low-band spectrum, or sub 1GHz, provides a broad coverage area with good building penetration, but lower peak data speeds. Mid-band, the spectrum between 1GHz and 6GHz, provides faster throughput than the low-band spectrum, but also has a reduced coverage area. It can reach peak speeds as high as 1 Gbps but is less suitable for building penetration. This band is highly coveted as evidenced by the $80B raised in the USA's C-Band auction because it provides a good balance between coverage, bandwidth, and speed. The high-band spectrum, often referred to as millimeter wave (mmWave), enables ultra-fast speeds and low latency. However, the coverage area is much smaller, and propagation is severely affected by foliage, physical obstructions, and rain, making penetration into buildings very poor. For these reasons, mmWave is often tied to small cells where pinpoint coverage can be provided when high bandwidth and critical applications requiring low latency are typically required.

Low-band spectrum
Frequency Range: Sub-1 GHz spectrum, such as 600MHz **Characteristics:** Provides broad coverage, good building penetration, and cost-effective deployment in rural areas
Mid-band spectrum
Frequency Range: Frequencies between 1 GHz and 6 GHz, such as 2.5GHz, CBRS and C-Band frequencies **Characteristics:** Provides faster throughput (up to 1Gpbs) and modest building penetration
High-band spectrum
Frequency Range: 28GHz and above; also called millimeter wave (mmWave) **Characteristics:** Enables multi-gigabit speeds (>1Gbps) and low latency. Limited coverage area compared to both mid- and low-band spectrum. Poor rain or building penetration

Table 1:
5G Frequency Spectrum

Spectrum ownership has driven the approaches taken in initial 5G deployments. Some operators have started with high frequency deployments (mmWave) to get a very high capacity, low latency network operating in high density areas. Others have started with a low frequency network (600MHz and now 2.5GHz) to get umbrella coverage first, with the understanding that the initial network will not be as fast as the high frequency solutions that will come afterwards. Most operators will use a blend of low-, mid-, and high-frequency spectrum to create their 5G networks.

Geography and demographics also play a role. Larger geographical areas are more cost-effectively served with low-band spectrum for coverage and capacity. Suburban areas are better served with mid-band spectrum due to increased bandwidth needs. High band will be used in densely populated areas and for critical applications due to the large amount of bandwidth provided by mmWave.

RAN architecture: Along with spectrum utilization changes, the RAN architecture is changing With 4G, the base station was separated into two parts – the Baseband Unit (BBU) for signal processing and the Remote Radio Head (RRH) for managing the RF transmit and receive signals This enabled network operators to expand the number of network access points (RRHs) without increasing the number of physical base station sites. The baseband processing functions were consolidated into a centralized, or master, station, which simplified radio resource management in HetNet or Carrier Aggregation environments.

In order to minimize the cost and footprint of equipment, mobile operators have been looking for ways in which they can centralize parts of the radio access network (RAN). To do this, the baseband processing unit (BBU) is moved to a central location from which multiple remote radio heads can be served. This separate location can house the BBUs for many different sites and can control all their radios remotely. This also permits upgrading the BBUs for different sites without having to travel to every site and reduces the amount of equipment that must be placed and maintained at each site.

With the introduction of release 15 of 3GPP, the functional split that started with the BBU and RRH in 4G (release 14) continues with better defined interfaces for the functional units. Release 15 better specifies the interfaces, functional building blocks and terminology, and defines what is called the NG-RAN. The NG-RAN consists of base stations (gNB) connected to the 5G core and to one another. The 5G network architecture splits the functions of the 4G BBU into the following building blocks: a radio unit (RU), distributed unit (DU), and centralized unit (CU). These building blocks may be co-located or deployed in different locations. As an example, a network requiring low latency may deploy the RU, CU and DU in one location at the edge. For applications where low latency isn't a requirement multiple RUs may be connected to one DU, lowering network costs while providing acceptable performance.

Along with the new functional building blocks, 5G contains backhaul, mid-haul, fronthaul, and open interfaces. The interfaces defined in 3GPP are allowing for an O-RAN as well as a cloud-RAN architecture. The network split can take advantage of other technologies such as SDN, and NFV, which can allow a network operator to roll out new functions and optimize the network and functions without changing hardware at sites. All of these aspects of the 5G network will create a plethora of cloud computing application developments. Cloud utilization and MEC will change how networks access, store, move, and analyze data, creating more applications and transforming how businesses function.

MACRO CELLS

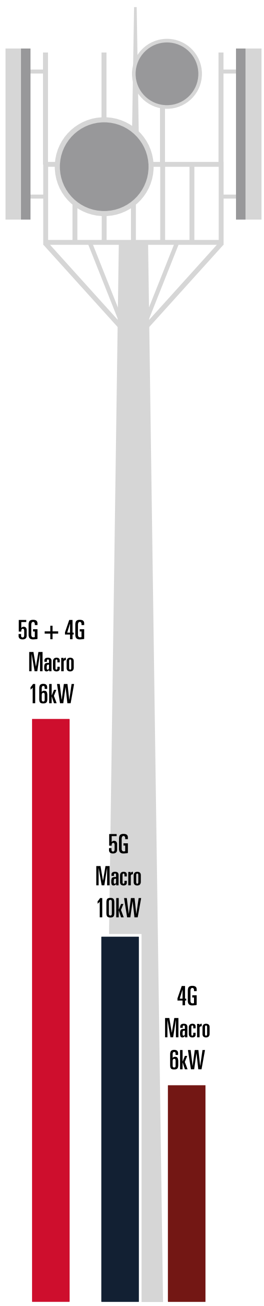


Figure 1:
Power consumption of 4G, 5G, and Combined Macro Site

The macro cell is the workhorse for wireless networks, providing extensive coverage from towers and rooftops. These sites are often large, containing multiple sectors and frequency bands. More than one generation of wireless technology (e.g., 3G, 4G, etc.) is often installed at the site. The different configurations result in power consumption that can range from a single kW at a smaller, single-carrier site up to 30kW for large, multi-generational sites.

While some new macro sites may be built specifically for 5G, most of the 5G capabilities will be additions to existing 3G and 4G sites. Sunsetting the 3G equipment will provide some space and power capacity for 5G upgrades. But with many operators planning to decommission their 3G networks in 2022 and beyond, there will be little space and power relief from 3G for 5G builds in the near.

Adding 5G capabilities to existing sites presents challenges to the MNO. The obvious concern is the availability of physical space on the tower for the antennas or radios and at the base of the tower for radio equipment. In addition, the added weight requires structural analysis, which often requires modification of the towers. Existing shelters (huts) may have some available unused floor space. But often, new site support and battery cabinets or huts may be needed to house the 5G addition.

Unless older equipment is retired, the addition of 5G capabilities increases the amount of power needed at the site. In fact, the total site power consumption could nearly double with the addition of 5G equipment[4]. Figure 1 shows the typical power consumption of a 4G site equipped with a 3-sector, 12-radio antenna, a 5G site with massive MIMO technology, and a site combining 4G and 5G. These numbers will vary considerably, of course, but do provide an indication of the power demands of 5G.

Upgrades to both the AC/DC power system and backup battery systems are required. Moreover, the MNO or its agent must determine if there is sufficient electrical AC power from the grid to power the site. If not, adding electrical capacity from the utility might cause significant delays to the deployment.

When located at sites with active 3G and 4G equipment, the 5G radio equipment often needs to be mounted in outdoor

4 https://urgentcomm.com/2020/02/27/powering-5g-cell-sites-may-rack-up-big-costs-for-operators/#:~:text=According%20to%20Chris%20Nicoll%2C%20principal,have%20always%20been%20fairly%20substantial.

cabinets. This is frequently the case even if the site is a “shelter” site, simply because there is no space available in the shelter. Cabinet arrangements vary significantly. A cabinet may include radio equipment along with the DC power equipment. Another cabinet may include the batteries for backup power. Still other cabinets may be available for expansion, either for power and distribution or for batteries. In addition to size and protection from the environment, the cabinets require thermal management systems to ensure the proper temperature is maintained to ensure optimal performance.

Power requirements for macro sites vary significantly. For instance, sites in rural areas may consist of 3-sector, single 4G radios per sector, with total power

Figure 2. Typical 5G Site Support Cabinet

consumption of 1500W. Adding a single radio per sector of 5G at 600MHz might double the power, increasing it to 3000W. In this case, adding AC/DC rectifiers and batteries is simple, provided there is space in the shelter or cabinet. Even when existing enclosures are out of space, cabinets that house radio equipment, power and batteries are available and straightforward to engineer and install.

In an urban site along a highway intersection, there may be 15-20kW of 3G and 4G radios. Adding multi-frequency 5G on top of that may add another 15kW. This situation is much more complicated as new shelters or multiple power cabinets and battery backup cabinets may be needed to power the 5G addition.

Battery backup also varies greatly. In the past, the amount of battery reserve was defined by operators, varying from 3 to as much as 8 hours in the USA. In Europe, the battery reserve was typically 2 hours or less. And in Africa, some sites were built for completely off-grid without batteries. Instead, they depend on diesel generators and solar operation.

During the early deployment of 5G, the use of battery backup has varied by operator, region, and application. When 5G has little to no backup, the operator relies on 4G equipment, which is often backed up, to provide a convenient fall back in the event a power outage drops the 5G equipment. Some European operators depend on this approach as they forego adding any batteries to 5G. This is expected to change over time as users become more dependent on the low latency capabilities of 5G.

UPGRADING THE POWER EQUIPMENT AND ENERGY STORAGE DEVICES IS MORE THAN SIMPLY ADDING RECTIFIERS AND BATTERY STRINGS

Another variable with battery backup is the type of battery. Many operators are interested in Lithium Ion because it does not occupy as much space as lead acid batteries. Lithium batteries are still 2X-3X more costly than the most advanced type of lead acid batteries using Thin Plate Pure Lead (TPPL) construction, an ongoing obstacle to widespread adoption. Lithium will eventually become more prevalent as cost, transportation, and storage issues are addressed.

Power up the Tower

Upgrading the power equipment and energy storage devices is more than simply adding rectifiers and battery strings. Prior to 4G/LTE, RF and baseband processing was performed in the base station in a climate-controlled room, cabinet, or shelter. The 4G/LTE architecture separated out the RF functions and the signal processing into separate network elements – the remote radio head (RRH) and the baseband unit (BBU). This change in architecture provided flexibility, improved RF efficiency, and saved on site and power costs. It also allowed the RRH to be mounted on top of the tower near the antenna to reduce transmission line losses.

5G macro cells use the same approach with the remote radio unit (RRU). During the initial wave of LTE deployments, radiated power could be in the 100's of Watts and a DC power draw as much as 300W. RRUs today can be dual band, or tri-band, may contain active antenna arrays, and radiate larger amounts of RF power. Current RRUs draw between 1kW and 2kW of DC power. The increase in power consumption is expected to continue as the network continues to migrate.

To complicate matters, the RRU is typically 100 to 200 feet away from the power equipment and can even exceed 400 feet. To deliver power to the RRU, power losses in the copper conductors must also be overcome. One way to accomplish this is to decrease the electrical resistance of the conductors by increasing the size of the power conductors. This effectively decreases power losses in the conductors and allows the RRU to be powered. However, increasing the size of the conductors can add significant cost increases in copper and installation time. The added weight of the copper may trigger structural analysis and reinforcement of the tower, adding even more cost to the deployment of the RRUs.

Another option for overcoming the power losses in the conductors is to increase the supply voltage from the traditional –48Vdc. To meet the requirements of the Safety Electrical Low Voltage (SELV), the voltage cannot be raised above 60Vdc (it doesn't matter if the voltage is + or -). To allow for some tolerance, power equipment vendors are using a constant 57Vdc or 58Vdc. The increase in voltage reduces the current flowing through the conductors, which in turn, reduces the power loss in the conductors. This allows for the use of smaller and less expensive conductors to power the RRUs resulting in significant CapEx and OpEx savings.

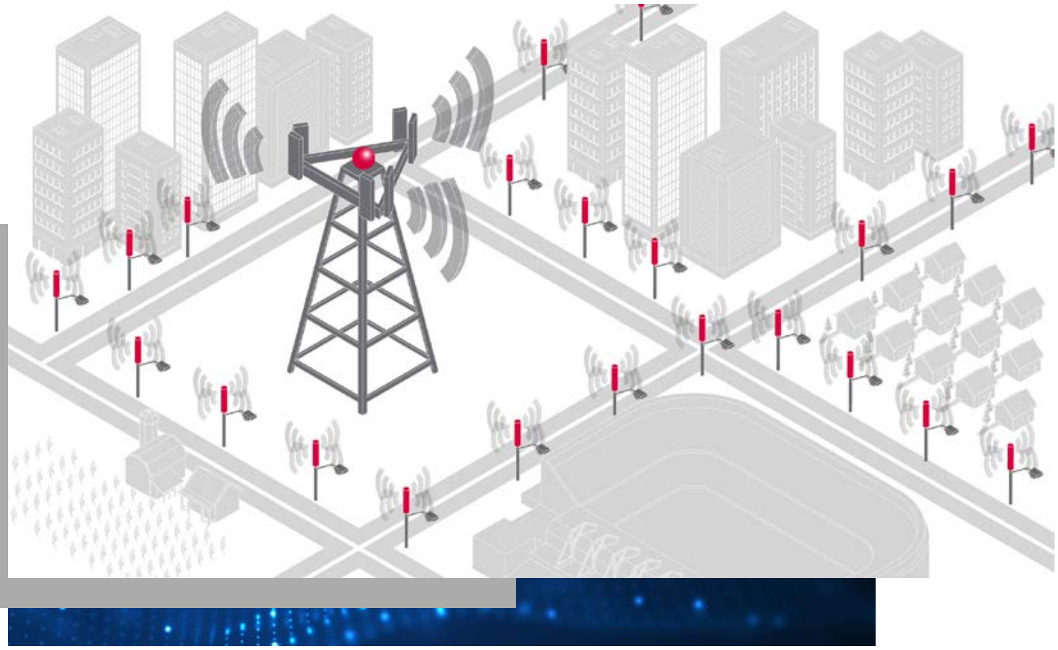
Larger tower sites available in many countries represent a potential for new use cases. 5G equipment at the base of the tower occupies less space than previous generations. As older generations are retired, the vacated space may be available for use in non-traditional or non-telecom applications. For example, dedicating that space to additional energy storage not only increases battery reserve time for the telecom site itself, but might also provide backup or peak shaving opportunities for EV charging stations, residential microgrids or industrial applications. This is a potential source of additional revenue for tower companies or telecom operators in markets where the grid is overloaded or the conversion to an alternative energy grid.

Ohm's Law and RRHs

With respect to power, voltage and current are inversely proportional when the resistance value is a constant (V=IR). An increase in voltage will reduce the amount of current flowing in the circuit.

Power is equal to the square of the current times the resistance ($P=I^2R$). The lower current results in less power loss in the conductors. By raising the voltage, the current is reduced resulting in a smaller amount of power being lost in the conductors. The fixed power consumption of the RRU and power sourcing of the rectifier allow the operator to use higher resistance cable. Since cable size is inversely proportional to resistance, a higher resistance cable is physically smaller and less expensive.

Conclusion: elevating the voltage of the power equipment enables the placement of the RRU at the top of the tower with connection made by smaller cables. The cost is reduced by avoiding the replacement of existing cables with larger ones with greater cross-sectional area. The costs savings are multiplied since the tower does not have to be configured to carry the additional weight of the larger cables



OUTDOOR SMALL CELLS

Another key element in 5G deployment is the small cell. The Small Cell Forum defines a small cell as, "… a radio access point with low radio frequency (RF) power output, footprint and range. It is operator-controlled, and can be deployed indoors or outdoors, and in licensed, shared or unlicensed spectrum[5]." Like macros, small cells also vary in size and capacity. They have the added complexity of various mounting options (pole, curb/street, wall, strand, etc.) as well as different techniques for delivering power to the small cell site.

Like their 4G predecessors, 5G small cells cover much smaller geographical areas than macro cells. Deployed in a distributed manner, these devices shorten the distance from the end user to the network. Their proximity to the end users enhances latency while they offer bandwidth rates similar to base stations. Pinpoint coverage and an increased number of available connections also make small cells ideal for use in IoT networks. Small cells are essential elements in the successful deployment of 5G.

5 https://www.smallcellforum.org/what-is-a-small-cell/#:~:text=Small%20cell%20definition,licensed%2C%20shared%20or%20unlicensed%20spectrum.

SMALL CELLS CAN RANGE FROM ALMOST FULL MACRO CAPABILITIES TO VERY SMALL STRAND-MOUNTED RADIOS

Small cells can range from almost full macro capabilities to very small strand-mounted radios. These radios are often deployed with the radio heads mounted remotely from the baseband units. Power consumption per site can range from 50W to over 1kW depending on the type of small cell and the application.

Since many small cells are required to provide blanket coverage in an urban setting, operators face many common concerns such as siting, permitting, and backhaul. These three issues are highly visible, often taking precedence to another challenge – getting power to the devices. On the surface, getting electricity to the low power small cells should not present a problem for operators with expertise in powering macro cells and other wireless network elements. But, the high quantity of small cells and their placement throughout an urban district or neighborhood create a unique challenge for the operator.

The obvious solution is to tap the electrical grid to deliver power to the small cell, a technique referred to as Local Power. This is an ideal solution when AC is readily available. Locally powered small cells installed on utility/jurisdiction owned poles account for most of today's deployment.

A local power supply is typically installed inside a cabinet suitable for outdoor deployment on a pole or wall. The power supply can take a single connection to the grid and supply power to multiple radios at the site. To minimize pole attachment fees, the power cabinet may contain a service entrance rated main breaker for utility disconnect as well as a load center equipped with breakers to disconnect individual radios.

Often, however, there is not straightforward access to the grid. In these scenarios, it can become very expensive and time-consuming to obtain a drop (i.e., an electrical line running from a utility pole to the small cell). There are two main alternatives. Some cable operators offer their networks as a means of delivering power to the small cell. These networks are called Hybrid Fiber Coax (HFC) networks, with fiber optic cables connecting the Head End to the neighborhood or business area, and coaxial cables providing the connection to the end user. These coaxial cables are energized to supply power to cable devices.

In North America, these HFC networks pass the vast majority of homes and most of the businesses. They are often coincident with the location of a small cell. Some small cells with a wide input voltage operating range can connect directly to the HFC network for power. For other small cells, tapping the power from these HFC networks requires a gateway device to convert the power for use by the small cell. When a gateway device is used, the HFC network provide the addition advantage of providing backhaul for the small cell. The gateways support DOCSIS® (Data Over Cable Service Interface Specification) communications standards. A DOCSIS modem associated with each small cell enables data backhaul through the HFC network. Many DOCSIS 3.1 devices provide 1 Gbps to support backhaul. The latest DOCSIS 3.1 standard provides upstream speeds of up to 10 Gbps, which is expected to be implemented for widespread 5G small cell backhaul.

Another alternative to local power is called Remote Line Power. This method uses a single, centralized connection to the electrical grid and distributes DC power to the small cells via telephone cables. These cables may be existing telephone wiring or new cables. If new cabling is deployed, the cables often take the form of composite fiber/copper cables with both media in the same sheath. The benefits of remote power include the possibility of a single AC access connection to the grid, a single power meter, and the ability to easily deploy batteries at the central site to provide backup for all connected small cells.

Historically, industry standards bodies have restricted the amount of power delivered per cable pair to 100W. This level ensures safety for the technician and the public. But newer distributed small cells are consuming much more than a few hundred Watts, making the Remote Line Power solution unwieldy due to the amount and size of the cables needed. The industry standards groups have begun investigating new technology, called Fault Managed Power Systems, which feature the ability to shut down current flow before an injury can occur. This technology will enable remote power to be delivered to devices consuming hundreds of Watts of power. The standards and products solutions are expected to be available in 2022.

THE BENEFITS OF REMOTE POWER INCLUDE THE POSSIBILITY OF A SINGLE AC ACCESS CONNECTION TO THE GRID, A SINGLE POWER METER, AND THE ABILITY TO EASILY DEPLOY BATTERIES AT THE CENTRAL SITE TO PROVIDE BACKUP FOR ALL CONNECTED SMALL CELLS.

MOBILE CORE

The core network, or mobile core, is the central part of the overall mobile network, responsible for managing all the mobile voice, data, and Internet connections. It has evolved significantly with each generation, transitioning from a combination of circuit switched and packet switched domains in 3G to the 4G networks' Evolved Packet Core (EPC) that uses the packet-switched technique for mobile data as well as voice calls. With 5G, the core is transitioning again, this time to the cloud native 5G Core Service Base Architecture (SBA).

Powering the mobile core is changing as well. The original Mobile Switching Center (MSC) relied on -48Vdc power plants like circuit-switched wireline telco central offices. The powering scheme began to change with the introduction of packet switching where many, if not most, of the data devices such as routers and switches are AC-powered. When first introduced, inverters could be added to the -48Vdc line-up to deliver the AC power. Now, with the growth in IP switching, so many of the devices used in the mobile core are AC powered that Uninterruptible Power Supplies are becoming the prevalent powering solution. In many ways, the mobile core is starting to resemble a traditional data center with rows of data equipment powered by UPS's backed up by specialized strings of batteries.

EDGE COMPUTING

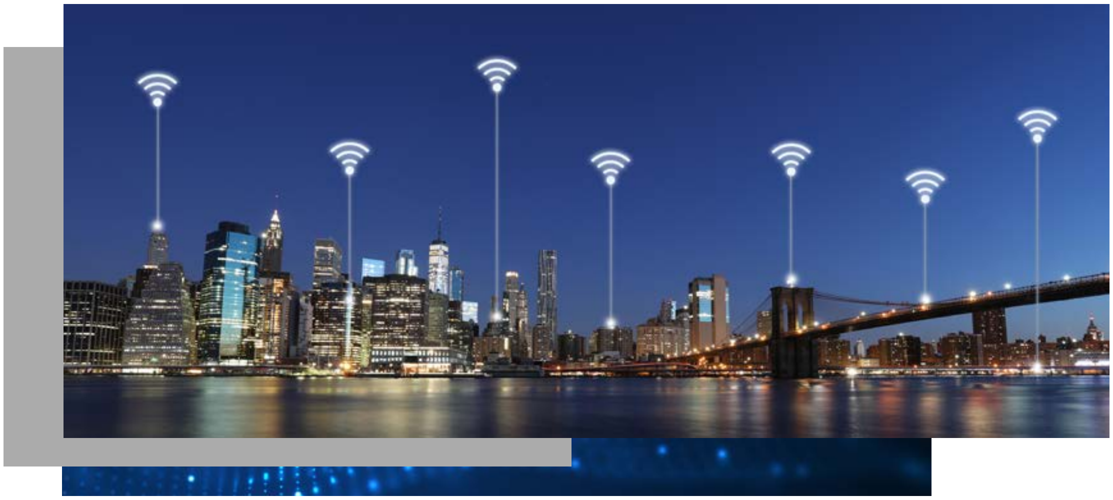
Edge computing moves cloud computing capabilities closer to the edge of the network, in close proximity to mobile customers and enterprises. It follows the evolution from LTE and the EPC to 5G NR and the next-gen core. The benefits to users include lower latency and higher bandwidth, both key elements for successful implementation of 5G services. Network operators also benefit from device processing and data offload.

Edge computing capabilities may be located at a central site such as a data center, on a customer's premises, in the RAN at a macro site, or eventually in the radio itself.

Like the Mobile Core, the edge compute function may be powered by an inverter connected to the -48Vdc plant or by a UPS backed up by batteries and a generator. in data center environments, dual A/B feeds may be deployed by the service provider. If so, the loads, i.e., the data equipment, are connected to two redundant power sources, with each source including its own UPS, batteries, cabling, and generator.

Edge compute solutions are expected to evolve with the network, continuing to move even closer to the user and further towards the nodes of the network than today.

EDGE COMPUTE SOLUTIONS ARE EXPECTED TO EVOLVE WITH THE NETWORK



PRIVATE 5G NETWORKS

Only a decade or so ago, most offices had wired desk phones and wired computers. Even laptops were connected to wired Ethernet for access to the LAN. Wi-Fi was available in conference rooms but was not universally deployed throughout the venue. During this time, cell phones in offices buildings were used primarily for voice calls or text messages.

2G and 3G wireless communication was transmitted on cellular bands primarily in the spectrum below 2.1GHZ, and in many cases at 850-900MHz. The lower the frequency, the better a signal can penetrate a building's wall, so the primary way operators provided wireless coverage indoors was to blast a large area of office buildings with high powered signal from a regular macro cell site.

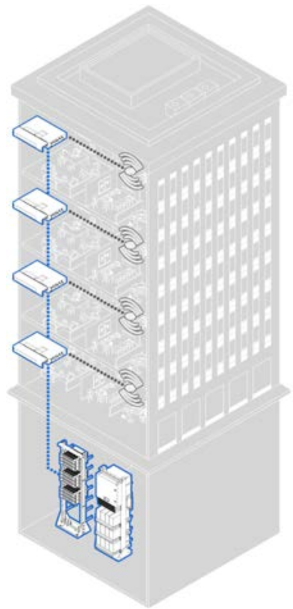
Fast forward to today, when cell phones are used for everything, indoors and outdoors. Voice communication and text messages are still prominent, but now emails, web searches and videos are considered essential to daily business life. In addition, laptops and tablets connect wirelessly, either via Wi-Fi or a direct cellular connection. With mobile devices becoming the primary communication tool outside or inside the office, they have in many cases replaced office phones completely.

An indoor setting – office building, arena, factory, etc. – can have hundreds or thousands of wireless connections, each requiring sufficient bandwidth to provide web and video access. The older method of blasting low- or medium-band wireless communications no longer suffices due to the tremendous increase in bandwidth demand.

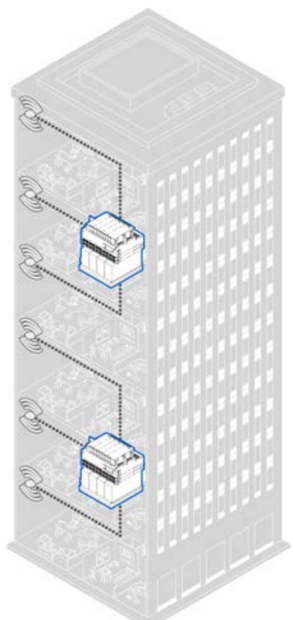
For 5G operators, a potential alternative is to use the higher frequencies such as mmWave. But these higher frequencies do not penetrate walls of buildings as well as lower frequencies do. To overcome this obstacle, operators have to place the antennas inside the building closer to the users. This results in the antennas being spread throughout the building, often on each floor.

Due to practical and electrical reasons, running antenna cables around a large office building is not feasible. At first, Distributed Antenna Systems (DAS) were deployed to connect radios via fiber cable back to a base station. The DAS technique has given way to indoor small cells, which are similar to their outdoor counterparts but with shorter range. Small cells with integrated antennas are typically placed on each floor to provide a small coverage area limit interference between these radios.

These indoor small cell radios come in many wireless protocols (e.g., Wi-Fi, 4G, 5G) and with a wide range of frequencies. They are small in size and rather inexpensive, so several of them can be placed on each floor to provide full coverage for the whole building.



Private 5G networks centralized power solution



Private 5G networks distributed power solution

Indoor small cells are low power devices, with power consumption ranging from 10's of Watts up to a few hundred Watts for larger devices. Power Over Ethernet (PoE) is a prevalent powering method for today's indoor Wi-Fi access points. PoE+ (formally known as IEEE 802.3at) delivers up to 25.5 Watts per device. That is not enough power for indoor small cells. Some might be able to be powered by PoE++ (IEEE 802.3bt standard), which can supply up to 71 Watts. More often, indoor small cells require more power than any current form of PoE can deliver.

AC-powered small cells may be powered from a regular AC outlet. This is not as straightforward as it sounds, as the outlet needs to be away from the public to ensure the small cell is not accidentally unplugged. Moreover, small cell placement does not always coincide with the location of an outlet, meaning construction and electricians are required to power up the device.

An alternative approach is to power the small cells using DC delivered from a centralized location. The DC power source may be located in either in a basement equipment room or in a telecom closet on the floors. At the central location, the commercial AC electrical power is converted to DC, connected to copper cables (e.g., 18AWG), and delivered via the

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cabling to the small cell where it connects directly to the inputs of the device.

For indoor applications, there are rigorous standards to ensure the prevention of fire and electrical shock. The IEC (International Electrotechnical Commission) standards limit indoor DC voltage to 60Vdc or less. The National Electrical Code® in the US further restricts power to no more than 100 Watts per cable. This requirement ensures safety for the public and technicians and provides sufficient protection for fire prevention. The NEC refers to this type of electricity as Class 2.

Remote DC powering provides many benefits. The copper cabling can be run alongside the fiber that backhauls the small cell signals. It can be placed on the floor, in the ceiling, or behind walls to ensure separation from the public. It is energy efficient and also provides a centralized location where batteries can be installed to provide battery backup for all the connected small cells. The AC equivalent would require small UPS's to be placed at each small cell site to provide backup.

Not all indoor wireless is truly "indoors." For example, arenas, stadiums, and campus facilities are also categorized as indoor applications. The Class 2 solution does not work for each of the connections in these settings. Instead, outdoor remote line power is often used to deliver power from a main area (e.g., headquarters building) to the other buildings in the campus. This same technique is used to power radios scattered throughout an arena.

With the proliferation of more 'smart' devices installed in newer buildings, the demand for more power will continue to rise putting pressure on the industry to find an alternative powering architecture. Various industry standards groups are looking into development of standards to meet these requirements. For example, the National Fire Protection Agency (NFPA) is looking to amend the National Electrical Code in North America to include a new class of power (referred to as Article 726 Class 4 (CL4) Power Systems). The standards and products solutions are expected to be available by 2023.

CONCLUSION

Delivering 5G service requires changes to traditional network elements and facilities. The changes in spectrum, the massive number of connections, and the requirement for close proximity require transformation in existing elements like macro cells and the mobile core, and new additions like 5G small cells and edge computing. In each case, there is change required for the powering solutions.

Operators have to deploy large UPS and the batteries that support them in order to energize the newer AC-powered data equipment. The macro cells require more 48Vdc power along with elevated voltage to reach active devices at the top of the tower. Batteries must provide more energy for the space they occupy, and cabinets have to incorporate this all into a thermally managed, environmentally protected enclosure.

Powering small cells is changing as well. The smaller, strand mounted 5W radios may be powered by a local power supply or remotely via copper or coaxial cables. For larger small cells, or street macros, new remote power technology is needed along with revised standards to ensure the safety of the technicians and public.

The 5G power architecture is undergoing a transformation that will turn power from a hurdle to an enabler.

About the Authors

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