5G Field Deployment: Practical Considerations

The fifth generation in wireless mobile communications, 5G NR (New Radio), has a new, more efficient over-the-air format. 5G can operate in both RF and millimeter wave bands, bringing higher data rates, reduced latency, increased reliability, lower energy consumption and greater system capacity that allows more devices to use the network than ever before. The first deployment of 5G leverages the existing 4G LTE core network, while a full 5G implementation is not expected until 2021. The deployment of 5G presents many changes that carriers have to consider in order to deliver a high-quality of service to their end-users. In this paper, we present the underlying technologies behind these changes, and what specifically needs to change as part of the 5G NR base station.

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Cellular Evolution

Cellular technology has evolved considerably over the past few decades. Consequently, the term cellular no longer adequately describes the full capabilities of today's modern mobile networks; hence the term broadband is now used.
Mobile broadband networks add levels of complexity with each new generation. Expectations are for 5G networks to improve quality of service (QoS) and enhance data transmission speeds via increased bandwidth by handling more tasks in milliseconds. To achieve this, modern mobile broadband networks have to know what radios are around them, what carrier any given device is on, be ready to process voice or data, understand when to hand-off the carrier or hold on, aggregate carriers to improve data throughput, and at any given moment handle an e911 call. It is a lot to ask a network to handle, much less a single site.

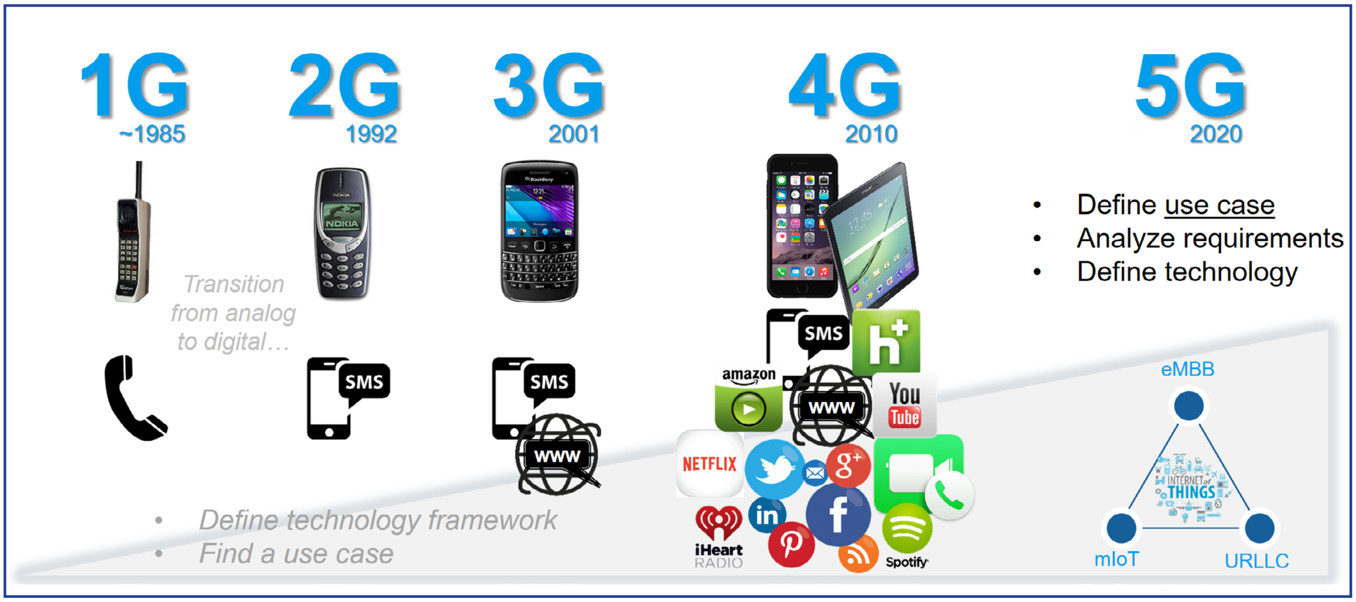


Figure 1: Evolution of mobile wireless over the past few decades, from 1G to 5G

First generation wireless mobile communications technology, 1G, was voice-only using analog radio signals. The second generation, 2G, used digital networks allowing for digital encryption of conversations, and provided more efficient use of the RF spectrum. Data services were added, including text messages, picture messages and multimedia messages (MMS). The third generation, 3G, was still predominantly voice-centric although it provided additional features such as mobile Internet access, caller ID and video calling. The basic hardware required to establish a typical wireless telecom station included a BBU (baseband unit), a radio and an antenna.

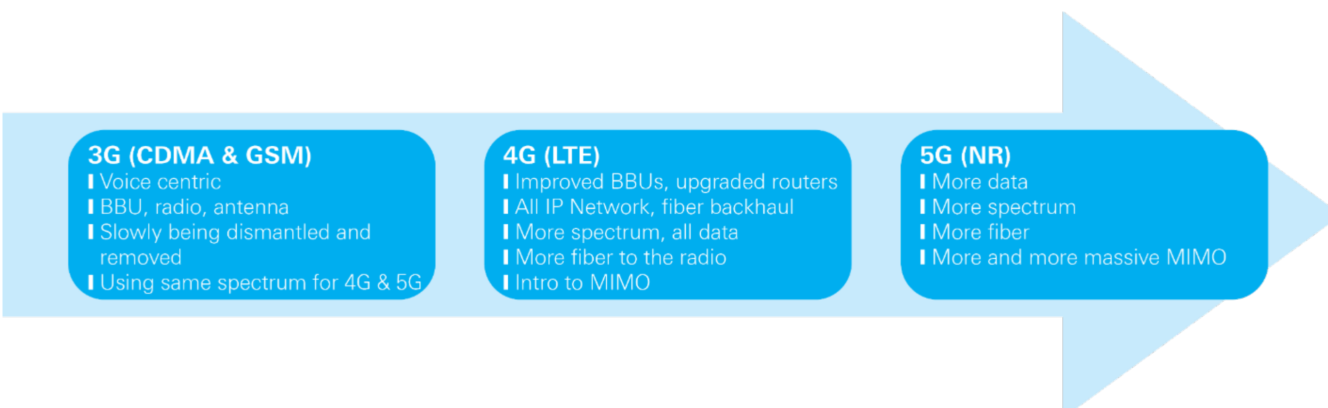


Figure 2: Mobile evolution from a voice-centric to a data-centric system

The next generation, 4G LTE (Long Term Evolution), provided mobile broadband Internet access to smartphones and to laptops with wireless modems through an all-IP network. The network became data-centric, and required additions to the wireless telecom stations such as improved BBUs, routers, fibers and multiplexers. Even voice services became data-centric, referred to as VoLTE (Voice over LTE). The same spectrum was used for 4G as had been used for 3G. MIMO (multiple-input and multiple-output) was introduced to multiply capacity by simultaneously sending and receiving more than one data signal over the same radio channel.

The fifth generation, 5G, advances the technology to a new level, one built specifically for data. 5G allows more data transfer and utilizes more massive MIMO to achieve a larger number of simultaneous connections. Faster speeds, improved efficiency, better coverage and higher peak capacity are all available compared to 4G. Latency is significantly reduced, allowing faster upload and download speeds.

New 5G networks will help to meet the needs of many diverse and unforeseen use cases such as augmented and virtual reality, industry automation, smart cities, self-driving cars, and much more.

Migration from 4G to 5G

Moving from 4G to 5G is a significant amount of work with significant challenges for network operators. This includes upgrades, expansions, new spectrum and major modifications. The 4G systems of today are going to migrate to 5G by replacing the radio heads and upgrading or possibly replacing the baseband unit (BBU). Upgrades to support a new spectrum means significant changes to each site. Specifically, the radios and antennas will need to be replaced with newer 5G equipment.

Typically, there is a domino effect of hardware that must be upgraded as changes are made to a site. New radios can also mean new fiber runs are required up to the radio. And more data may mean more fiber to carry it all. As new radios are added, more power is required. As a result, the power jumpers on the tower will need to be upgraded along with additional, or new, rectifiers at the sites. Additional rectifiers mean more batteries for backup power.

Even bigger changes include the expanded use of massive MIMO, primarily throughout urban areas. Massive MIMO is a revolutionary breakthrough in technology; the format enables networks to handle more data and more users. It also helps antennas become smart and more efficient. Smart antennas can do more than just radiate RF; they can also form radiation into narrow beams (beamform) directed at specific users.

The Massive MIMO system will have the radio and antennas combined into one unit, with many antennas in one package making up an array. For example, you could have an array of 16x16, 32x32, or 64x64 antennas. What that means is in the Massive MIMO unit there will be a matrix of 16 antennas across and 16 down giving us a total of 256 antennas in one unit. This allows the Massive MIMO Unit to do beamforming, and talk to multiples of users at the same time. Massive MIMO units will be a challenge to install on the tower, and once again, power and fiber will need to be upgraded to make the new radios work.

5G Networks: Use Case Driven

By design, 5G will meet the needs of customers with multiple use cases each with its own set of differing performance needs. For the first time, a new network is being designed and built end-to-end, and not just for the last mile. When a site is being built, it will be built with a specific use case in mind. It will be 5G, but the intended use case will determine how the site is designed:

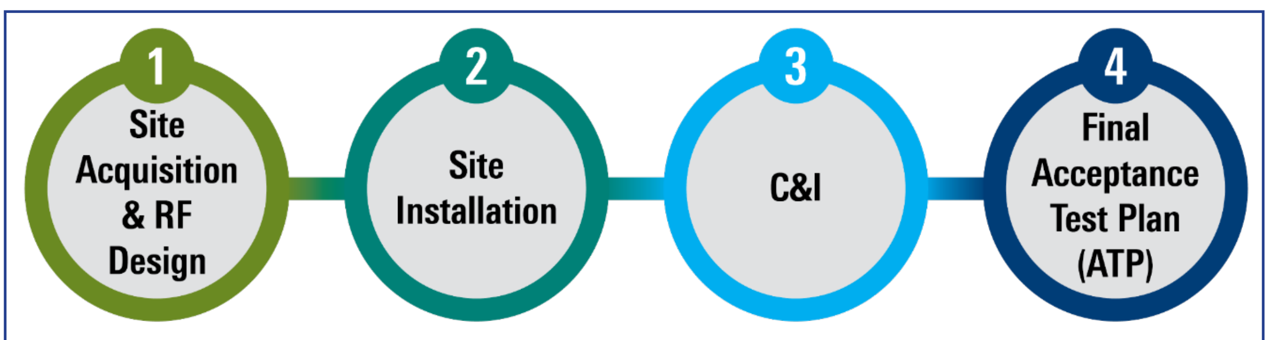
- To implement Enhanced Mobile Broadband (eMBB), massive MIMO units with a fiber backhaul would be required to handle the many users and traffic loads
- For Ultra Reliable Low Latency (URLL), an EDGE server installed at the site would be required to keep latencies as low as possible.
- Massive Scale Communications (uMTC) improves connection of devices that are in planes, trains, automobiles, etc. Millions of devices talk to some other device, classic IOT M2M

To meet these performance options, the architecture of the site changes dramatically based on the intended application or use case being served.

Typical Deployment Process

Deploying a wireless system is a step-by-step process. There are many involved, sometimes difficult, steps throughout the process that must be completed and approved before the system can be used. These same steps apply no matter the size of the deployment, whether it is a pole, a tower, a small cell, or something larger.

Although some operators may refer to these steps by different names, the flow is generally the same starting with site acquisition & RF design, and then site installation, commissioning and integration, ending with final acceptance test plan (ATP). Each one of these steps is described below.



▪ Site choices ▪ RF Coverage ▪ Review fiber maps and access	▪ Site walks, drones, and site-specific action plans ▪ BOM correction, verification, site specific BOMS ▪ Power, battery, RF, tower/rooftop, Shelter/cabinet	▪ Commission all equipment ▪ Integrate ▪ Site Acceptance	▪ Drive Testing & Acceptance ▪ Site goes live ▪ Cluster acceptance

Figure 3: Typical deployment process for a wireless site or base station.

Site Acquisition

The actual deployment process starts with site acquisition, which must happen before any actual construction can begin. Dealing with government agencies, permitting issues and leases for the chosen site can be the most time-consuming part of the overall process. Today, the majority of systems are upgrades or overlays of existing sites; but there are still many cases in which new sites must be added to address coverage issues.

RF design today looks at more than just RF coverage; in fact, that is only part of the study. RF penetration and strength is a significant design consideration, however, coverage problems cannot simply be solved with more power.

When doing an RF design, the spectrum determines the coverage and building penetration. Millimeter wave will not penetrate walls, trees, or windows. Thus, the sub 6GHz spectrum may not deliver the throughput required for many installations.

Site mapping is the process by which a RF design is obtained for existing sites or generated for new sites. Reviews of existing fiber maps show what is already in place, and what is needed. Once the design is complete, it will have to be verified and optimized under real-world conditions after the installation.

Site Installation

The next step is the site installation or construction process. As-built and architectural drawings of any existing towers provide a starting point, but they can often be out of date. Site walks are essential before construction begins in order to verify what is actually at the site. Site walks no longer require someone physically walking the site, but are now often done relying on newer surveys or drones to reduce time and cost.

As part of this step, site-specific lists are generated for the materials and equipment that need to be upgraded. Structural studies of the tower are critical to make sure the tower can hold all of the weight of the new equipment that must be added. Details such as shelters or cabinets to house delicate equipment must also be considered.

Commissioning & Integration

Commissioning and integration (C&I) is the next step. Commissioning, or powering up the site, is the step during which all of the equipment is tested to make sure it operates as expected. The system is not live at this point, but the BTS (base transceiver station) must be fully tested to verify it works properly.

The second part of this step, integration, occurs when site-specific information is added through an RFDS (RF design sheet). For the system to operate properly, part of this information contains a neighbor list of nearby cells, so the new cell site knows all of the other cells sites and sectors to which it will hand off and receive data. This neighbor list is specific to the site being deployed.

Final Acceptance Test Plan

The last step is overall deployment process is the final acceptance test plan (ATP). Once the neighbor list is uploaded, it is time to test the system. The ATP drives the testing process, when the handoff between sectors and between sites is checked. There are upload tests and download tests. It is important to verify that a site will not take down any other sites in the network or make them drop calls. There are also tests for E911 (Enhanced 911), which is an FCC requirement at every site that has mobility. Everything must work properly to pass final acceptance. Once each of these sites is accepted, then this group of sites, called a cluster, is also accepted, and the network can go live.

For the major carriers, such as AT&T, Sprint, T-Mobile, Verizon and others, this work must be repeated for every site; somewhere between 500 and 10,000 times, which explains why it can take a long time to deploy a wireless system.

5G Rollout Overview

In order to allow more data transfer, 5G networks require more spectrum, more bandwidth and more power. However, the first version of 5G are being designed specifically for data, where voice will be implemented using a solution called VoNR (Voice over New Radio), which should be released sometime in 2021.

This lack of voice capability in 5G creates a complication regarding the FCC regulation on E911 testing. At fixed wireless sites, a location is automatically linked to a 911 call, so a 5G system can be used there without causing any issues for E911. To use 5G systems on network sites that offer mobility and service smartphones, which are required to have E911, the lack of voice capability is resolved by building upon existing 4G LTE infrastructure and using VoLTE.

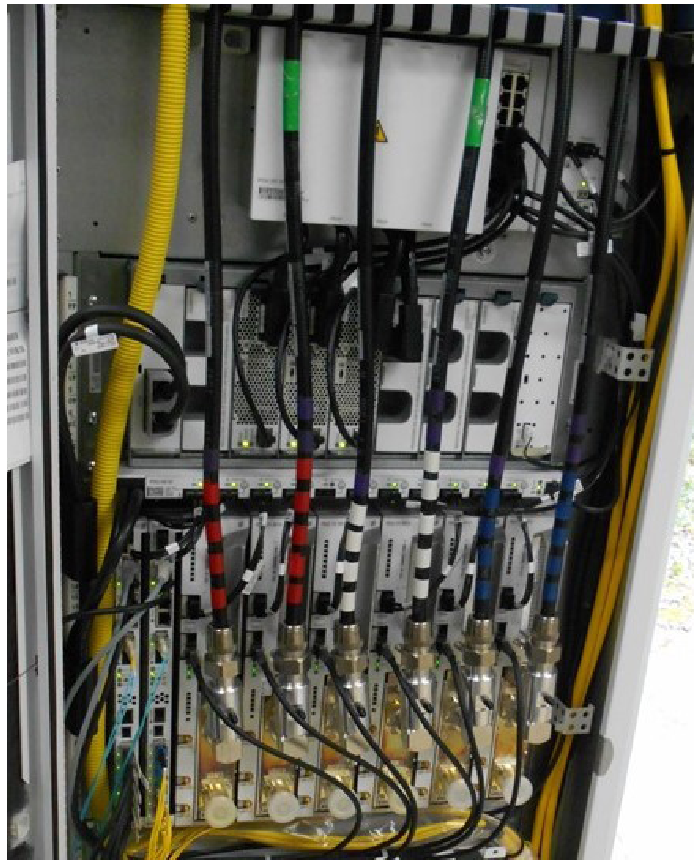
At present, many 5G networks are attaching to existing 4G LTE deployments and are sharing the spectrum that had been exclusively used by LTE. The enabling mechanism is dynamic spectrum sharing (DSS), which allows 5G NR and 4G LTE to coexist while using the same spectrum. DSS enables network operators to provide a coverage layer for 5G using the lower frequency bands used by 4G LTE. DSS is the method by which 5G deployments can meet the E911 requirement, allowing VoLTE to provide the location data needed for 911 calls.

As part of the 5G rollout, site-specific lists are generated for the existing 4G sites, listing the materials and equipment that need to be upgraded, as discussed in the following section.

Different from legacy technologies in the past, deploying 5G includes more than just installing a base station; 5G requires building a complex telecom solution. Many Tier 1 and Tier 2 carriers have broken down deployment into a series of smaller steps, where each step is project managed from beginning to end to ensure that the overall base station deployment meets its intended needs and everything works together properly.

Existing 3G and 4G LTE networks will not go away with the deployment of 5G networks. The existing equipment will be upgraded to allow 5G capabilities. The process is much more complicated than just adding a new BTS. As part of the 5G rollout, equipment both on the ground and in the air will need to be upgraded.

Considerations on the Ground



For most base station deployments, the overall job can be divided between changes on the ground and changes in the air. Below is a summary of considerations on the ground, where the equipment cabinets are located:

- BBUs will not always be at the site
- Routers are being upgraded,
- Backhaul is being upgraded
- Power needs to be upgraded,
- Site may need more batteries to maintain readiness
- Backhaul must be upgraded, requiring more data, more fiber
- More power required for more equipment

Of the existing equipment at most base station sites, the rectifier batteries and the router backhaul will need to be upgraded. The backhaul must be upgraded because more data requires more fiber. EDGE routers with upgraded fiber multipliers (fiber mux) can be installed at the edge of the network to enable better connectivity with the end-use applications and reduce system latency. The addition of more equipment requires more power, which also implies more batteries in order to maintain system readiness in the event of a power loss. Equipment cabinets are generally fully loaded (see above picture). So additions and upgrades need to be made on the ground, which may sometimes involve the cabinets themselves. The BBU has to be upgraded or a new BBU has to be added. However, this is not the only addition. Power upgrades have to happen prior to the site getting new equipment. It is a process. New rectifiers and batteries have to be added to support the additional equipment at the site.

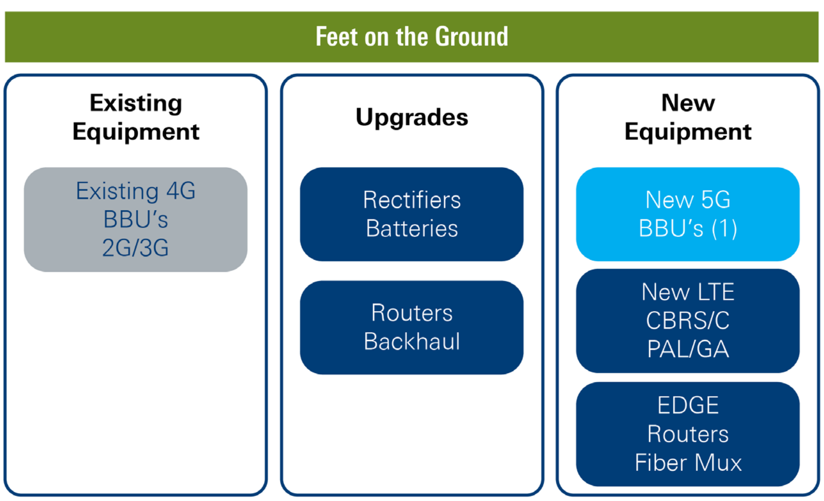


Figure 4: Summary of new and upgraded equipment required on the ground

With regards to the backhaul, new routers and fiber boxes or microwave hops have to be added to support the additional bandwidth requirements. It's not one thing at the site that has to be upgraded, but rather each contributing part.

Considerations in the Air

There have been considerable changes in the design and overall architecture of antenna systems in the last few technology turns. 5G is no exception. Below is a summary of considerations in the air, where the antennas are located:

- Additional antennas for new spectrum,
- Replace antennas with new antennas with more ports,
- New spectrum like mmwave will need its own antennas,
- Integrated antennas are the norm at higher spectrum
- Massive MIMO requires integrated antennas

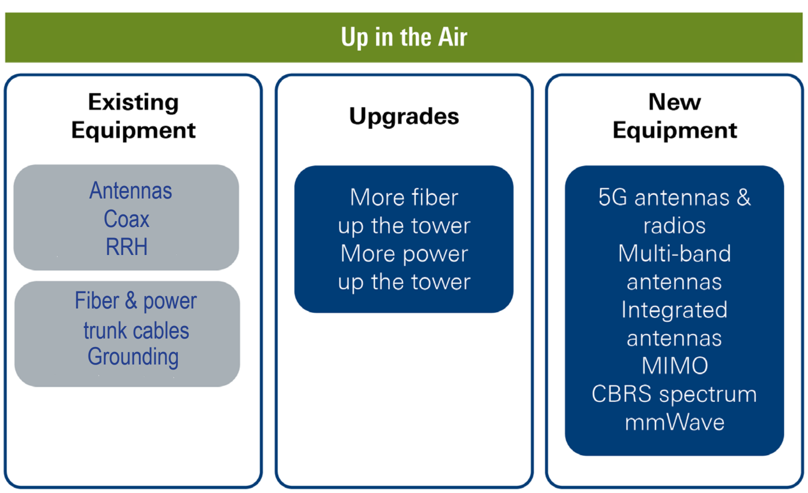


Figure 5: Summary of new and upgraded equipment required in the air

The release of new spectrum in the C Band (CBRS, or Citizens Broadband Radio Service), which refers to the spectrum in the 3.5 GHz to 3.7 GHz range, will probably require carriers to upgrade their routers. This new spectrum may also require new or additional antennas. The new antennas and radio heads may require more ports now that MIMO is commonly used. MIMO may require 4 to 16 transmit and receive ports. To accommodate MIMO, more RF ports will be required to improve throughput and coverage. That means more RF jumpers if the antennas and radio heads are not integrated.

New spectrum in the mmWave, the 24 GHz to 100 GHz range, will provide new challenges and require its own antennas. At this higher spectrum, integrated antenna systems, where the radio and the antenna are one unit, will become standard. Integrated antennas are already required by massive MIMO. The new spectrum will allow much more bandwidth and more throughput.

As new equipment is added, the existing radios and antennas may stay or, most likely, may be replaced with newer multiband antennas. Each spectrum and format will need to have a dedicated radio, where the radios will be connected to the antenna via RF jumpers. Unfortunately, it is not just one RF jumper per antenna or technology. Today, all carriers use some type of MIMO, so it could be 4x4 or 8x8. In FDD the 8x8 would actually have 16 RF jumpers, 8 for the transmit and 8 for the receive since the transmit and receive spectrums are separate. Whereas 8x8 on TDD, like CBRS, would only need 8 RF jumpers between the radio and antenna since TDD sends and receives in the same spectrum.

The exception would be an integrated antenna. That would be where the radio and antenna are one unit. Like the Massive MIMO units, they have integrated antennas. For example, a 64x64 consists of 64 transmit and 64 receive, which requires a lot of RF jumpers no matter what technology is being used.

Massive MIMO will most likely be used by CBRS, C Band, and mmwave. Sprint has already deployed Massive MIMO beginning in late 2019 and into 2020 before the merger with T-Mobile.

The Implementation of C-RAN

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 will reduce the amount of equipment that must be placed and maintained at each site.

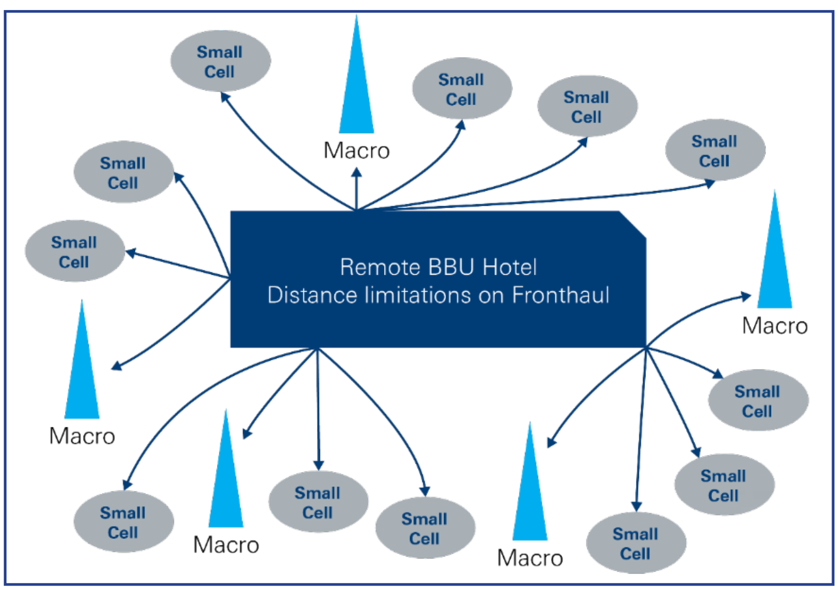


Figure 6: Diagram of C-RAN implementation

The advantages of implementing a C-RAN

- One control center
- Limited equipment at site
- Control many sites from one location
- Monitor from one location
- Fewer generators
- Fewer rectifiers
- More control

Testing 5G in the Real World

Extensive testing is needed for successful 5G deployment. Some of these testing requirements were covered in the section on the final ATP. Tests for the upload speeds, download speeds, throughput measurements and voice quality must be performed.

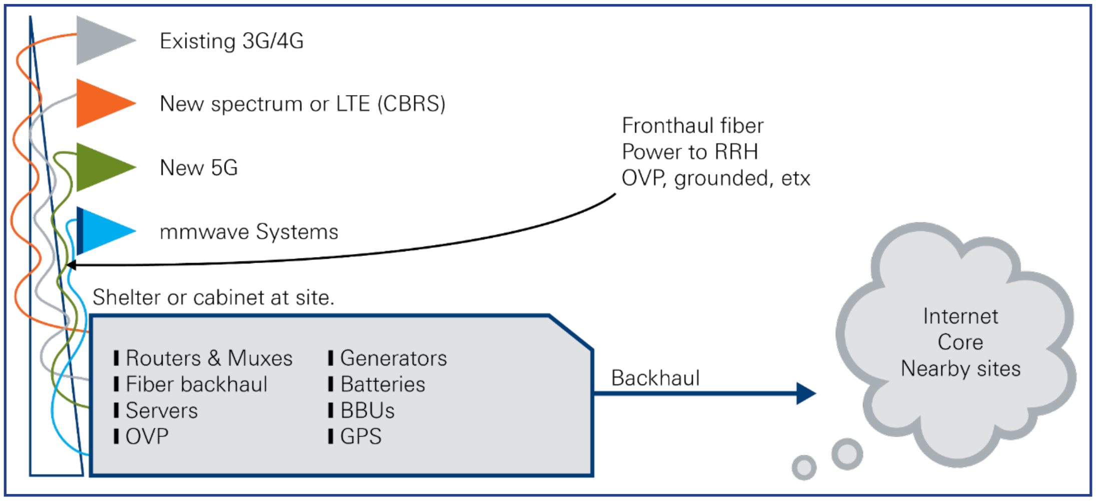


Figure 7: Diagram showing those items that need to be tested in a typical 5G deployment

Some of the specific items that need to be tested and verified are as follows:

- New 5G NR capabilities
- Data handoff between 5G and 4G (back-and-forth transfer)
- DSS between 5G and 4G for spectrum sharing (at present)
- Voice handoff to 4G (at present, using VoLTE); VoNR in the future
- Handoff between sectors
- RF coverage matching RF design parameters
- Signal strength
- Signal interference

The only way 5G can be deployed at present is by building on existing 4G LTE, so testing that the systems work well together (e.g., hand-offs, etc.) is critical to success. In addition, if there is still 3G at the site, the voice handoff has to work on the 3G equipment, per a FCC requirement.

PIM (passive intermodulation) interference can occur at a wireless network site. PIM is generally caused by physical metal connections. At a tower site, generally the RF connectors are the leading cause of the issue. To help minimize PIM, you can buy RF jumpers that are PIM tested and certified to help alleviate the problem. Many Tier-1 carriers make this a requirement. If you make RF connectors onsite, they should be tested for PIM.

Another common form of interference is self-interference, or interference caused by the site itself. Several situations can lead to self-interference. Sometimes it is due to poor or incomplete site planning. If the RF allocation is not planned properly and two nearby sites are using the same channel, then they will interfere with each other. The more common reason for self-interference is a poorly installed antenna. For instance, when the RF design is done, it assumes that the antennas have a specific down tilt. If an installer has the antenna facing straight out with zero degrees of down tilt, then the signal may travel for miles, hitting another site and all its surrounding users. All of this because an installer did not measure the antenna tilt or they didn't read the site-specific installation documentation, which is generally on the construction drawings (CD) or the RF Design Sheets (RFDS).

A major test of the 5G network is how well it performs in meeting the customers' expectations in terms of quality of experience (QoE). Is the coverage what they expect, is the signal strength strong enough, is the data throughput fast enough, are there any dropped calls, is there noise, and so on.

In addition to testing all the new equipment as it is installed, the legacy technologies at the site must continue to work as specified. If the design and installation is done correctly, with all the parameters and settings adjusted properly, then everything should work as expected. The handoffs, the throughput and the download and upload speeds should all be as expected. Everything must work together seamlessly for a successful deployment.

Testing Equipment for 5G Deployment

Every new installation needs to be verified to ensure correct network performance and ensure quality of service (QoS). For 5G deployment, Rohde & Schwarz offers a broad portfolio of products to ensure that a network is properly configured and deployed and meets all of its targeted performance and regulatory requirements. To learn more about Rohde & Schwarz products for 5G deployment and test, please visit the [5G network testing page] on the Rohde & Schwarz website [www.rohde-schwarz.com].

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Conclusion

The 5G wireless mobile communications network is built specifically for data, and it allows faster data transfer speeds, improved coverage, higher system capacity and lower latency than any network before. The initial deployments of 5G networks use the existing 4G LTE core network infrastructure, with upgrades to much of the existing equipment, and with dynamic spectrum sharing of the currently used low band frequencies. New spectrum in the higher frequency bands allows even more throughput, but requires more equipment upgrades. Testing of the 5G upgrades and the handoff between 5G and 4G is critical to success of the new network sites. Short-term, VoLTE is needed for voice in the new 5G networks, but will later be replaced with VoNR such that everything will be running on a true 5G NR network.

Definitions and Acronyms

- **BBU** is Base Band Unit is the processing unit for a BTS.
- **BTS** is a base transceiver station, basically the base station.
- **CRAN** could mean cloud RAN or Central RAN, both have a different meaning but look very similar. In both scenarios the radios are remote from the BBU connected by a mux and fiber or wireless. A Cloud RAN has part of the BBU processing in the cloud where as Central RAN has the BBUs for a large area in one data room commonly called a BBU hotel.
- **IOT** is Internet of Things, basically devices that talk to the internet automatically with or without human intervention.
- **LTE** means Long Term Evolution, basically the format for 4G. It turns out that long term was not so long after all.
- **M2M** means machine to machine and it is literally one device talking to another device, relaying data for a purpose.
- **MIMO** means Multiple-In Multiple-Out and allows the transmitter and antenna to send more than one signal at a time.
- **Massive MIMO** is a combining the radio and a smart antenna to talk to the end user.
- **MU-MIMO** is multi user MIMO, meaning that the multiple streams can talk to multiple users at the same time, increasing loading on the BTS.
- **OEM** is an Original Equipment Manufacturer, generally the company that makes the BTS hardware.
- **RAN** is the Radio Access Network is this is generally the BTS and backhaul.
- **U-MIMO** is single user MIMO. It has several streams of RF carrying data simultaneously talk to another MIMO device.
- **RRH** is remote radio head and is used interchangeably with RRU which is remote radio unit.
- **FDD** means Frequency Division Duplex is something that was used commonly in 3G. It's paired spectrum with an uplink band and a downlink band in their specific spectrum. For 1G, 2G, and 3G this was common so you could have a talk and receive channel in the system. There is a guard band in between the transmit band and the receive band. FDD was very popular with GSM and CDMA. It is very difficult to take advantage of MIMO antenna technology in FDD compared to TDD.
- **TDD** means Time Division Duplex is where there is one large piece if spectrum used for uplink or downlink. Any part or percentage can be assigned to be the uplink or downlink. If you have 20MHz of bandwidth available, then you're not locked into 10MHz up and 10MHz down like FDD. Instead, you have full control over how much goes up and comes down. The downside that some carriers had was the timing of the spectrum, and it's higher bands that have this. However, Wi-Fi spectrum is pretty much all TDD, and it works quite well for data. On the other hand, WiMAX used TDD, and it seemed to be taking off but it never fully blossomed and was cast aside for LTE. TDD makes MIMO technology easier to use because it is all in one band.

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Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

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