

HOW NETWORK TESTING ENSURES HIGH-QUALITY IN-BUILDING LTE AND 5G DEPLOYMENTS

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1 INTRODUCTION

The popularity of app services, particularly video streaming, among smartphone users is expected to result in a 10-fold increase in data consumption over the next five years. Most of today's mobile data traffic is generated indoors and this trend is set to continue into the future. While indoor use certainly includes users' homes, in this context it mostly concerns large offices, public buildings and commercial properties.

These buildings are often modern, with windows made of low-emissivity glass that reflect and absorb infrared and heat energy efficiently to improve indoor thermal control. Unfortunately, these types of windows are also very efficient at attenuating radio waves, causing degraded cell phone reception. This degradation affects all kinds of radio technologies and becomes more severe with increasing frequency. With LTE up to a frequency of 2.6 GHz and 5G up to around 4 GHz (not to mention mmWave frequency bands), the attenuation through this type of glass as well as other material is significant. To meet the needs of indoor communications via outdoor base stations, operators have to deal with an attenuation range of 20 dB to 30 dB, and even higher for higher frequencies.

Additional indoor base stations, such as small cells, address this issue and optimally benefit operators and users alike. But only if their installation is close to where additional capacity is required (i.e. close to people) and an SINR can be achieved that is comparable to the existing (macro cell) deployment. A high SINR results in high additional capacity created by the new base station. In conclusion, capacity expansion should ideally be implemented for indoor deployments.

This document deals with the entire indoor deployment cycle of mobile networks, such as distributed antenna systems (DAS) and small cells. It highlights the characteristics of these systems, the planning phase, installation and verification of the deployed system. And finally, it describes mobile network testing solutions to verify successful mobile network deployments indoors.

2 INDOOR DEPLOYMENT TYPES

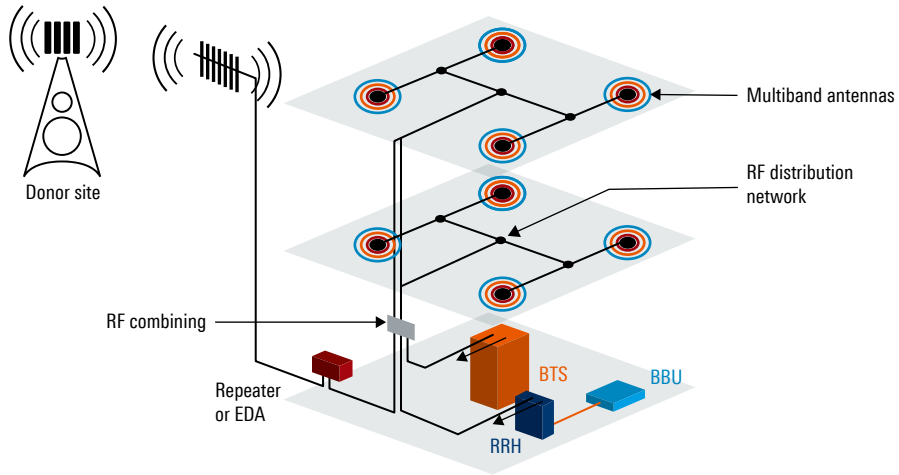
For indoor deployments, we generally distinguish between two models:

1. Distributed antenna systems (DAS) of various types such as passive, active and hybrid
2. Small cells, e.g. femto, pico and microcells

2.1 Distributed antenna systems (DAS)

2.1.1 Passive DAS

Figure 1: Passive DAS with a macro cell donor



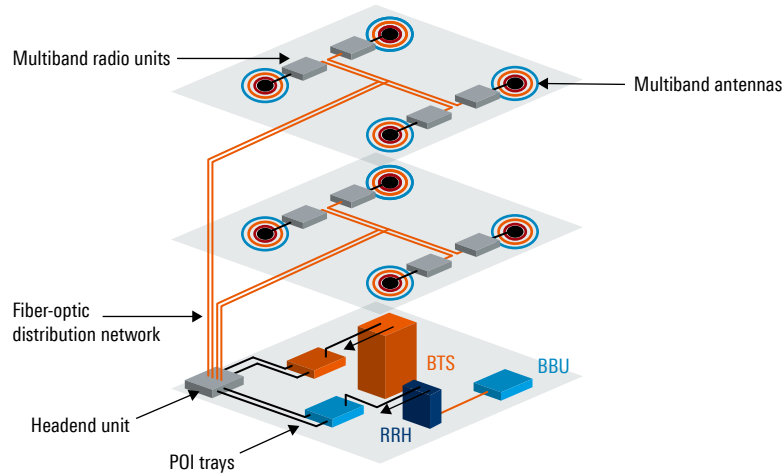
A passive DAS is a simple coverage solution for smaller buildings. The central idea of a passive DAS is that it takes the signal from a base station located somewhere in the building (e.g. basement) or remotely and distributes it through a passive network of splitters, cables and antennas inside the building. The DAS can also be connected via a repeater to an external macro tower (donor site) and distribute the repeated signal into the building. If the design allows, network operators and public safety organizations can share a passive DAS system, implementing multiple technologies and frequency bands through the passive cable, splitter and antenna network, much like over the air with long range radio systems.

Although the number of components required for a passive DAS is small, labor costs for installation can be very high. A passive DAS is also difficult to modify. This is due to the long length of semi-rigid coax cables used and the limited ways in which to adjust power at each antenna, which is necessary to ensure good coverage. Whatever is done to adjust power at one antenna will affect power levels at other antennas. The RF performance could be evaluated as low due to the mentioned high attenuation of RF cables, higher noise level that leads to a lower signal to interference plus noise ratio (SINR) and the high probability of passive intermodulation (PIM).

Errors or faults (e.g. a damaged antenna) are difficult to detect in a passive DAS.

2.1.2 Active DAS

Figure 2: Active DAS layout



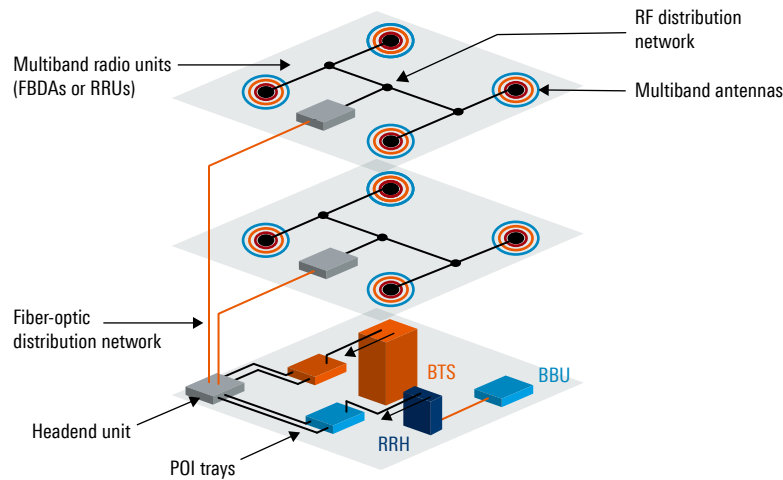
An active DAS may be created in many different configurations, but the one pictured above is very common. In this figure, a variety of transceivers, located e.g. in the basement of the building, generate RF signals on various bands. The RF signals are converted to optical analog signals, distributed on fiber to multiband radio units, converted back to RF and then transmitted from the local antennas. The terminal antennas and radio units may either be integrated into one physical unit or be separate.

Active DAS systems offer the greatest installation flexibility, since fiber is much easier to install and route than RF cable, and it is much easier to adjust capacity and power levels at each antenna for good coverage. They also provide a high level of flexibility in the selection of RF signal sources when adjusting cellular sectors.

However, active DAS systems are expensive. The equipment is significantly more expensive than the equipment for a passive DAS, and the multiband radio units take up a lot more space for the antennas at the host location. An active DAS offers flexibility after installation and during operation and, in some cases, may be the best solution.

2.1.3 Hybrid DAS

Figure 3: Hybrid DAS configuration



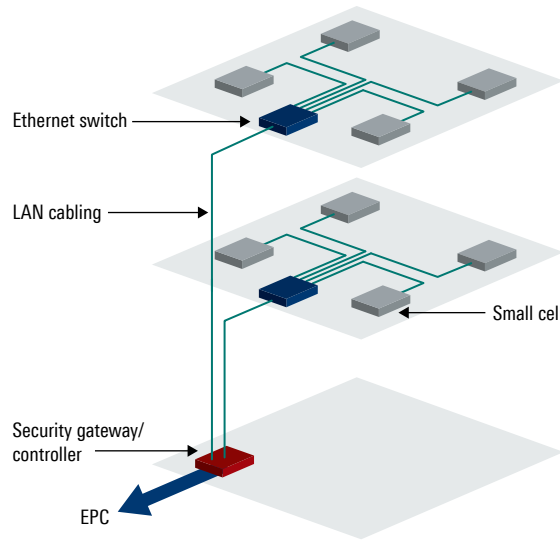
A hybrid DAS combines the benefits of both the active and passive DAS. The idea is to combine the flexibility of an active DAS with the lower cost of the passive concept. The hybrid approach can be cost-effective and at the same time improves cellular capacity. This is the most common type of installation in larger buildings and sports venues. In this case, the RF signal sources can be located in an equipment room somewhere on the premises and use fiber for the longer signal runs. Once the fiber reaches the desired floor, stadium section or other endpoint, a multiband radio unit is used to convert the optical signals back to RF and then the RF carriers are routed through a local RF cable, splitter and antenna network. This section, from the multiband radio units to the antennas, is often referred to in the industry as a “branch”. The base of the branch, the multiband radio unit, is referred to as either a fiber bidirectional transceiver (FBDA) or a remote radio unit (RRU).

While a hybrid DAS is less flexible than an active DAS and will have a slightly higher noise figure, it is better on both counts than a passive DAS, and it is less costly than an active DAS.

2.2 Small cells

Small cells are small base stations with lower transmit power levels. The umbrella term “small cells” encompasses all kinds of base stations that are smaller than macro cells.

Figure 4: Small cell network



In a small cell network, each small cell adds a new cell with new capacity (depending on the achievable SINR) and coverage. Air interface resources are reused in every small cell. The cabling in buildings with a small cell network is predominantly LAN, which is very easy to install compared with RF coaxial cable, also by less-skilled personnel.

Small cells offer very high RF performance (no attenuation on cabling, low noise, low PIM probability and consequently a high SINR) and huge flexibility. A small cell deployment is often more cost-efficient than a DAS system (at least for a single operator deployment). To avoid network failures, small cells are typically auto-configured by the operations support system (OSS) or the self-organizing network (SON).

There is no silver-bullet indoor solution that is superior to all other solutions. Depending on the strategy and needs of the operator, either DAS systems or small cells are deployed.

2.3 Steps for efficient implementation of indoor deployments

Typically, indoor deployments comprise three phases:

1. Network planning and design (planning)
2. Installation and commissioning (installation)
3. Site acceptance (verification)

To maximize efficiency, these steps are performed in two visits to the site. During the first visit, the site survey, which includes careful planning based on planning tools, is conducted. Potential locations of antennas proposed by planning tools and cable paths need to be verified. In special cases, test transmitters are tried and RF signals are investigated using network scanners to verify the planning for critical sites/floors.

During the second visit, the small cell is installed and commissioned and, finally, accepted by verifying that the expected and planned performance in terms of coverage and capacity is met.

3 PLANNING

3.1 Planning phase – general

Successful and cost-effective planning of small cell deployments requires planning tools that ensure maximum reliability and accuracy. This, however, is not always the case as floor plans might be outdated and change records of live deployments not properly updated.

Well before the site survey takes place, an indoor deployment must be designed in a back office using planning tools to capture and centralize customer requirements. For example, with the help of the industry's leading indoor planning software supplier iBwave which uses a file format supported by Rohde&Schwarz measurement solutions.

Typically, staff conducting site surveys are more experienced in handling tasks concerning RF, base stations or antennas than those installing the small cell during the second visit. Site survey engineers use planning software offering floor plans, proposals for the location of the cells, simulated coverage and capacity predictions, etc. They verify potential locations of antennas proposed by planning tools and check that cable paths can be realized as planned.

Reliable indoor small cell planning with a test transmitter and network scanner takes place during site surveys for critical sites.

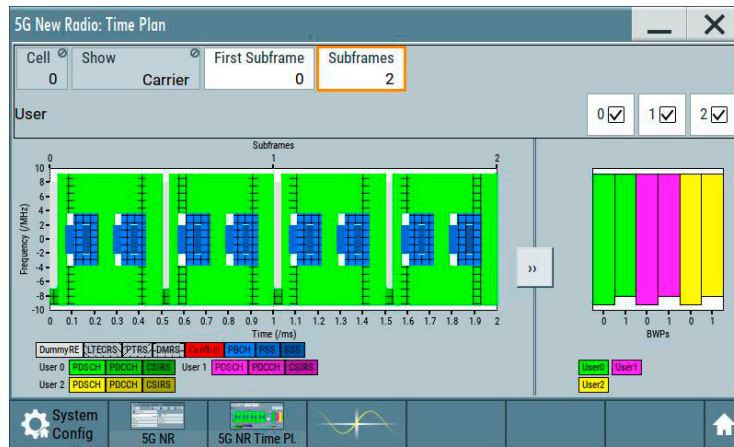
3.2 Process for critical sites

Reliable planning of small cells is essential for important and critical deployments, e.g. hospitals, manufacturing facilities or VIP (CxO) office floors and meeting rooms (the list of examples is endless). The planning phase for critical sites and locations entails the verification of the initial plan during the site survey. The technician records the actual situation without the planned small cell/antennas. To collect this information, he simply takes a measurement using a network scanner. A network scanner is a passive measurement tool that receives and decodes all RF signals from all cellular technologies within all configured frequency bands. A mobile phone, on the other hand, has a limited number of receivable signals due to the SIM card, is less accurate and is unreliable with respect to measurement repeatability.

The in-building scanner measurement will probably result in signals with a low reference signal receive power (RSRP) and low signal to interference plus noise ratio (SINR) from the macro outdoor LTE or 5G networks. While the RSRP indicates the coverage at the measurement position, the SINR value indicates signal quality in relation to interference. With poor coverage and low signal quality, only a low data throughput can be expected.

Following the scanner measurement, the technician verifies the planning by emulating an LTE or 5G installation with test transmitter.

Figure 5: 5G signal time plan, set up with a signal generator from Rohde & Schwarz



When employing a test transmitter, it is important to use the correct band intended for the deployment. Technicians need to be aware that they are transmitting in licensed bands that might belong to another operator.

We recommend using the frequency that is owned by the operator who intends to install the indoor system. With the test transmitter up and running, further scanner measurements of selected band(s) will show vastly improved RSRP and SINR values, despite the low power of the test transmitter.

3.3 Continuous wave versus modulated signal when testing

Continuous wave transmitters generate narrowband signals (tones) at a certain frequency and they are usually less expensive than transmitters that generate modulated signals. However, a receiver measuring the received power on this frequency will detect the CW signal and all other available signal components from other sources on this frequency. The advantage of transmitting a 5G modulated signal by the test transmitter is that the receiver can measure the receive level of exactly this signal by demodulating the test transmitter signal.

Yet, to perform a proper performance prediction, specific and technology related information is required in the form of coverage (e.g. RSRP in 5G) and capacity figures (e.g. SINR in 5G). Only these figures help predict the performance (data rates/capacities) of a planned small cell. Consequently, a test transmitter is required to transmit modulated signals with a typical wider bandwidth.

4 INSTALLATION

4.1 Installation phase – general

Following successful execution of the network planning and network design phase, the most critical phase of small cell deployment now begins: the actual indoor installation and commissioning. Many subscriber issues originate in the antenna system. Reasons for that could be reflections in the antenna system caused by damaged cables, or poor positioning of antennas, which results in a poor coverage due to zone overlapping.

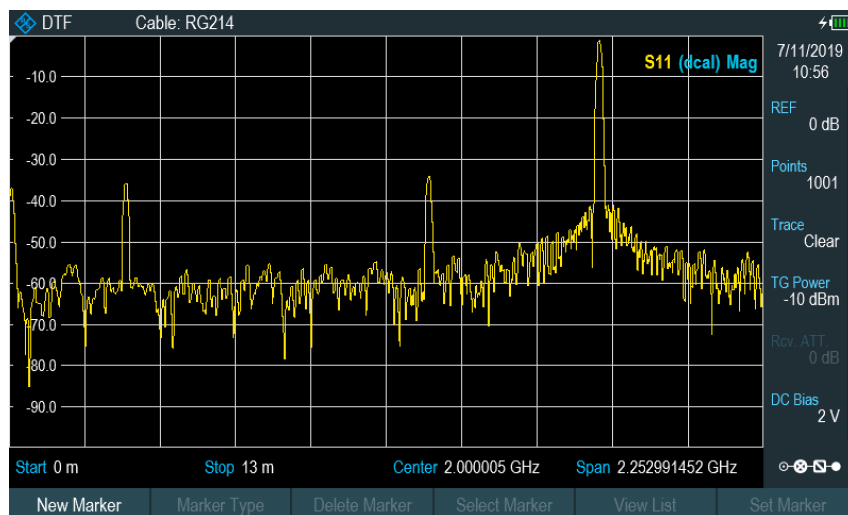
Many of these faults do not necessarily trigger an alarm at the operations support system (OSS), at least not until a critical level is reached. Consequently, these errors could remain undetected by the network for a long time, causing a “silent” degradation of site or cluster performance and subscriber services.

For this reason, it is important to have a high-quality indoor installation and detailed tests right from the beginning. Performing measurements after each implementation is therefore usually the only way to ensure that both the network quality and the planned capacity increase will be achieved.

4.2 Installing antennas and cables

From a pragmatic point of view, the sooner a problem is identified and addressed, the easier and less expensive it is to solve the problem. In passive and hybrid DAS, for example, technicians should always test the RF cable and antenna to avoid installing damaged goods. Sounds logical, but this step is often skipped, with the assumption that this would save time. Now, just imagine the extra effort needed to change cables that have already been installed. Cable loss and distance-to-fault (DTF) measurements do not take long. Problems with cables can be easily and quickly located with a cable and antenna analyzer. In the screenshot below, you can see a distance-to-fault measurement. The peak on the right side shows the end of the cable, in this case the measurement was executed while the end of the cable was open which results in total reflection. Typical return loss values are 20 dB, which means that 99% is transmitted and only 1% of power is returned. 60 dB is close to a perfect match (almost no reflection). A common system limit is 15 dB or better. In Figure 6, the level of the reflected signal is close to a perfect match with 60 dB, with the exception of two prominent peaks. The two peaks are better than 15 dB or 20 dB, but such a sudden reflection can only be explained by an error if no connector or similar is located at the respective distance. In this case, insulation damage is the cause.

Figure 6: DTF measurement, recorded with R&S® Cable Rider ZPH



During indoor installations (also applies to outdoor installations), it pays to focus on the quality of workmanship to achieve a high network performance and quality. While linking connectors, it is important to make sure that cables are cleanly cut and connector surfaces are spotless so as to prevent passive intermodulation (PIM). Little things, such as cleaning connectors with isopropyl alcohol instead of blowing on them, can make a huge difference (our breath is moist and can start corrosion on connectors).

4.3 Testing the entire antenna system

The location of the new antenna has already been specified by the planning tools. During installation, however, it is important to consider all objects in close proximity.

Despite the low power levels of an indoor antenna, metal objects, such as mounting structures or air conditioning pipes, that are illuminated by the antenna can generate external PIM. Moving the antenna slightly, however, can considerably reduce PIM effects and maintain the planned coverage. Ideally, the site survey should already have taken these topics into account. If PIM cannot be reduced sufficiently by moving the antenna, the objects must be covered with absorbers that prevent PIM from occurring.

Following installation, reflection measurements should be performed to assess the complete antenna system. The return loss indicates how effectively the antenna radiates the energy (a high level of reflected energy significantly limits the site performance and can even lead to transmitter damage). Cables that might have gotten pinched or broken during installation have a negative impact on the overall return loss.

DTF measurements can help locate and correct these faults. Actually, these measurements can be carried out by using predefined test sequences, so that even non-technical staff can perform them quickly and efficiently without having to worry about missed measurements or incorrect settings. Static and dynamic PIM measurements help verify that the new cell does not generate undesired intermodulation products affecting the network.

5 VERIFICATION

5.1 Verification phase – general

After the careful planning and actual installation of a new indoor network, it is time to verify the commissioned indoor deployments and ensure quality of experience (QoE) for the end users. Both are best achieved using a commercially available smartphone that is designed for reliable indoor deployment verification and also features dedicated testing functionalities for final site acceptance.

5.2 Tips for indoor verification

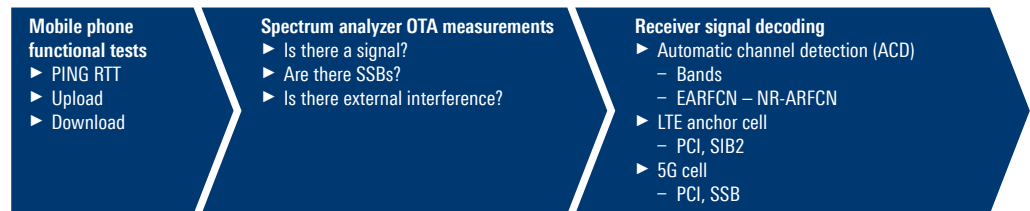
Ideally, the verification of small cell indoor deployments should take place immediately after their installation. The installation and commissioning of the network is typically performed by technicians who are less trained in matters concerning RF, base stations or antennas than the personnel responsible for the site survey during the planning phase.

To verify indoor deployments efficiently and effectively, a walk test is recommended covering complete floors of e.g. the building with the new network installation. Correct and simple reporting is key in enabling the installation and verification engineers to prove that they have fulfilled their tasks.

The tools used by the installation and verification team should support software that is specifically designed for the planning, mapping and design of indoor systems. The supported software should provide predefined floor plans, locations of the cells, simulated coverage and capacity predictions, etc.

5.3 Site acceptance/troubleshooting procedure

Figure 7: Site acceptance procedure

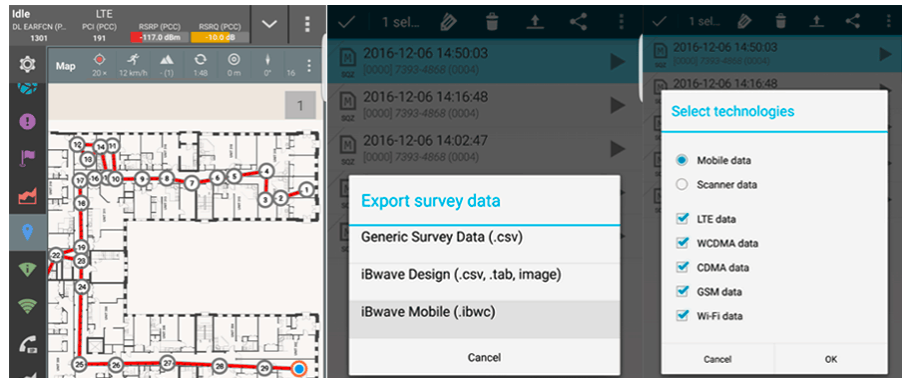


These are the three phases of a complete site acceptance procedure. The procedure begins with mobile phone functional tests. In case of issues, OTA measurements need to be executed for further investigation. If the performance is not optimal or doubts still exist, troubleshooting with measurement equipment that is able to decode received signals is required.

5.3.1 Mobile phone functional tests

The best and easiest way to perform the functional test is by using a smartphone. Ideally, the smartphone and in particular the prepared software on the smartphone should support the project file format of the specialized planning, mapping and design software (like that from the global vendor iBwave Solutions) to ensure that data such as collected measurement results can be exchanged quickly. Exactly this case is shown in the following images. Measurements are performed based on a predefined floor plan. It is then possible to convert the result file directly into the iBwave file format and export it.

Figure 8: Measurement performed by QualiPoc Android based on iBwave floor plan, data exported as .ibwc file



Performance tests based on floor plans are only one part of the deployment verification. Basic network tests are another. QualiPoc Android offers the functional tests required, compiled in a compact site verification option that includes predefined test jobs and report generation. This optional and handy site acceptance test is a set of very basic tests, including:

- ▶ Setting up a call
- ▶ Pinging a server
- ▶ Downloading/uploading a file to check throughput

In addition, the user can add project related information and classify KPIs. During the test, a simple GUI keeps the user informed about progress and test states. After each test, a report of all relevant results and information obtained with the site acceptance test is generated.

The following screenshot (Figure 9) shows an example of a zone overlapping measurement and an antenna health check.

The zone overlapping measurement is based on zones from the iBwave planning tool and checks the overlap of the different zones, highlighting it in the color of the overlapping zone (in purple in the example shown in Figure 9).

The antenna health check (Figure 10) offers a very efficient antenna check to verify that all antennas are properly installed and working as expected. In the controller/agent setup, each agent is locked to a band of the DAS network. A threshold is specified for the signal strength or signal quality, you then walk through the area and can immediately see where the signal strength or quality is sufficient and where not.

Figure 9: Zone overlapping test, QualiPoc Android

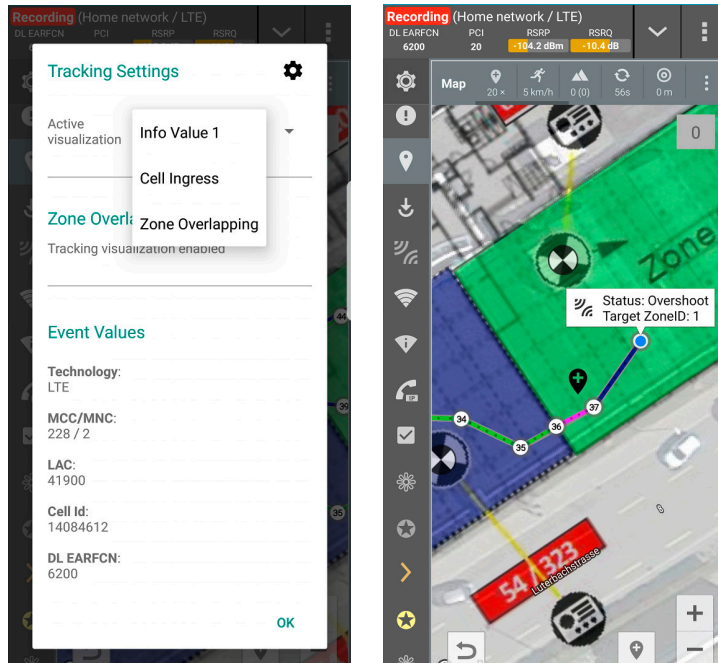
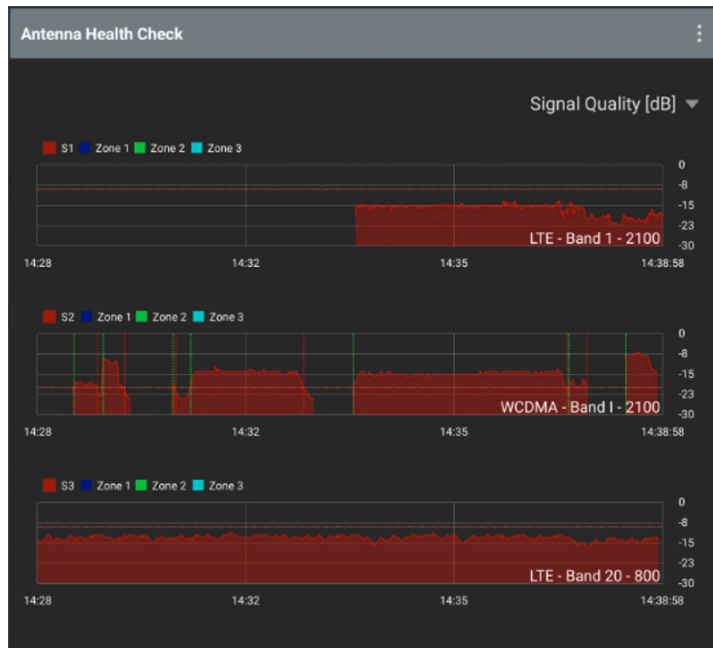


Figure 10: Antenna health check, QualiPoc Android

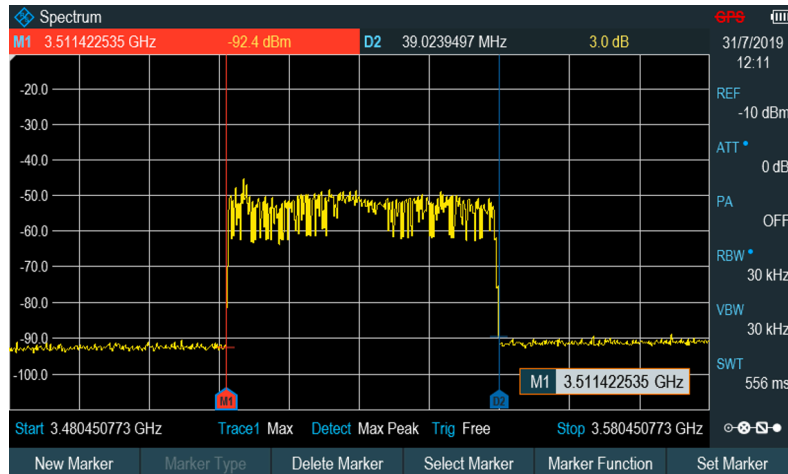


5.3.2 Spectrum analyzer OTA measurements

If any of the previous measurements have a different outcome than expected, the next step is to take measurements using a spectrum analyzer.

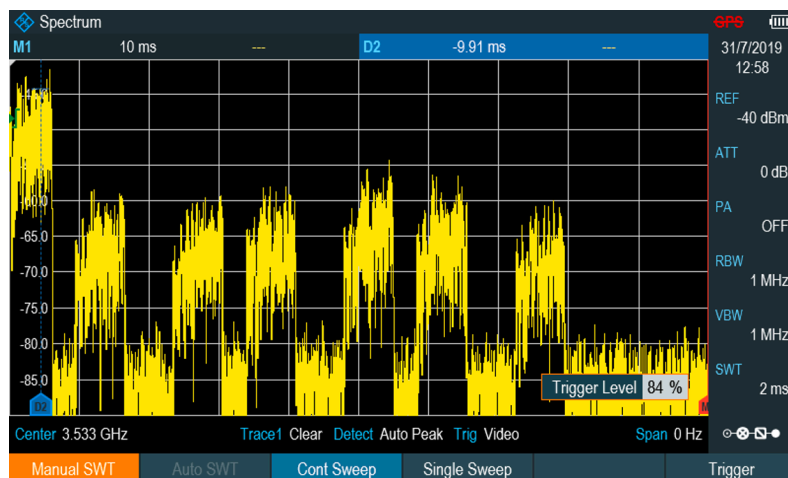
First of all, we need to verify that the signal (e.g. 5G signal) is really transmitted by the base station. This is done using a spectrum analyzer (ideally with a max. hold function and an OBW function to allow the occupied bandwidth to be examined).

Figure 11: Recorded with R&S®Cable Rider ZPH



Now we need to check whether all synchronization signal blocks (SSB) are receivable. This is done using a zero span function. Set the center frequency to the center of the SSB block and switch to zero span. The SSBs should then be visible. Figure 12 shows seven SSB signals in the time domain.

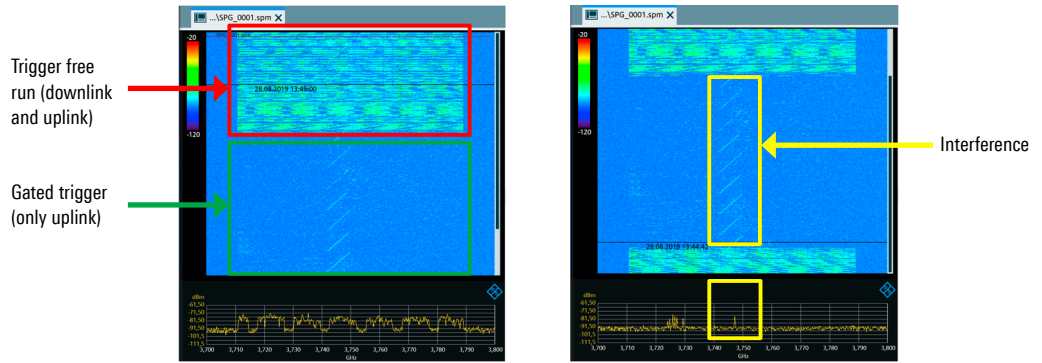
Figure 12: SSB in time domain, recorded with R&S®Cable Rider ZPH



The question remains whether any external interferences impact the network performance. Therefore, we need to examine the uplink for interference. In TDD networks, the downlink covers the uplink (on the same frequency) for most of the time so that it is very difficult to identify interference in the uplink direction, which is the weaker link, and the uplink interference affects the whole cell. Separating the uplink from downlink with a gated trigger will reveal interference, if there is any. The gated trigger function allows you to set a time gate that only visualizes UL areas of the signal. The red marked area in

Figure 13 shows mostly downlink signal masking effects on the uplink. When the gated trigger is switched on (green area), only the uplink slots are visualized and interference can be clearly identified.

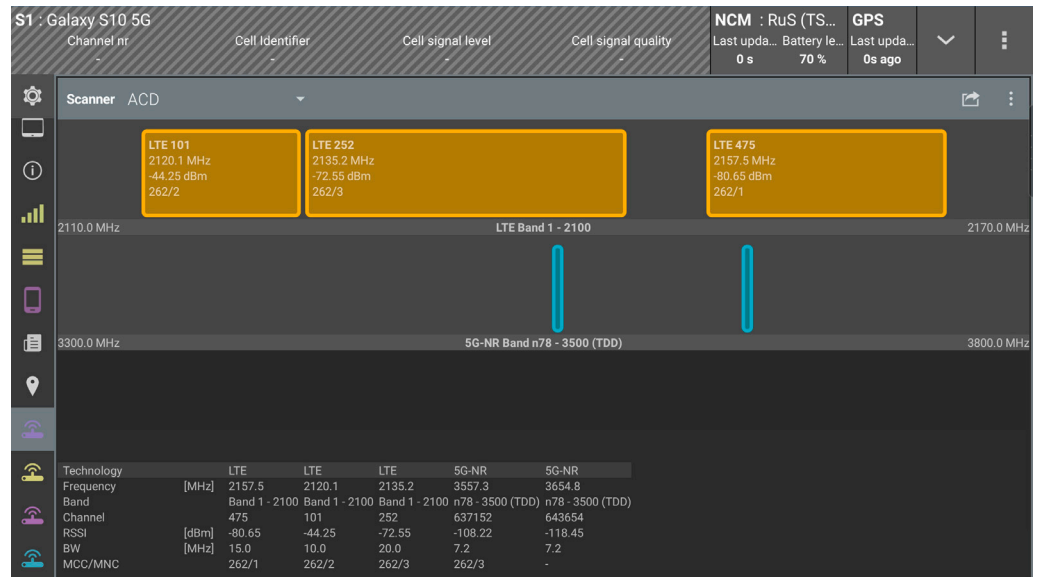
Figure 13: Gated trigger, recorded with R&S® Cable Rider ZPH



5.3.3 Receiver signal decoding

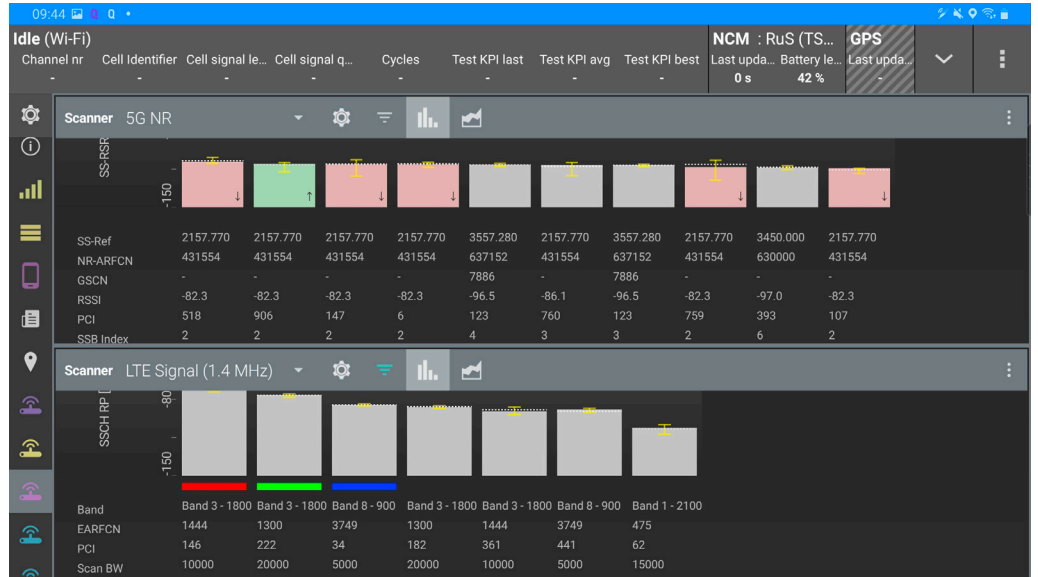
After the uplink, we examine the downlink details. An automatic view showing all available signals on the air interface including e.g. the accurate SSB frequency in 5G in the specific bands is beneficial for identification. Bear in mind that the SSB and its precise frequency are often difficult to find in running networks. Figure 14 shows such a view with three LTE signals in band 1 and two 5G signals in band n78.

Figure 14: Automatic channel detection, recorded with QualiPoc Android in combination with 5G site testing solution



We now want to take a look at the deeper information either in LTE or 5G. In the following screenshots you can see the information you should check if an error persists in the installed indoor network. Figure 15 shows 5G and LTE signal analyses. In 5G NR, every signal received is displayed with the PCI and SSB index. All LTE signals are also shown with the PCI. In both 5G and LTE, important parameters such as RSRP and RSRQ are measured; these can be viewed by scrolling down.

Figure 15: 5G and LTE signal analysis, recorded with QP Android in combination with 5G site testing solution



6 SUMMARY

In-building networks are a very good way to improve cellular network performance in buildings in view of the high attenuation of materials (glass, walls) due to the higher frequencies used for 5G (3.3 GHz to 4 GHz, or even mmWave frequencies such as 28 GHz or 39 GHz).

Passive/active DAS and small cells all have different pros and cons and operators/landlords must select the most suitable solution on a case-by-case basis. No matter what in-building solution is chosen, the installation cycle has to be supported with network tests to achieve a high network quality and performance.

It is important to have a structured installation cycle (planning, installation, verification) so that certain errors are avoided from the outset during planning and installation. It is much more time consuming and costly to fix errors once the system has been installed. It is also more difficult to detect errors during operation, because error messages are only sent to the network operation center when a certain threshold is reached. One way to detect errors early on is the DTF measurement, which should be carried out before cables are installed.

Rohde&Schwarz offers a full range of network test solutions for all cellular technologies including 5G to support the different phases of the whole process.

Combining our Rohde&Schwarz 5G site testing solution with the R&S®SGT100A signal generator (adding an external amplifier in case a higher transmit power is required) enables engineers to measure performance effectively (coverage and capacity) and to accurately verify the optimal location of the new small cell.

The Rohde&Schwarz 5G STS, including R&S®TSMA6 scanner and QualiPoc Android, and an R&S®Cable Rider ZPH cover the whole site acceptance procedure. The R&S®Cable Rider ZPH is also used in the installation phase for detecting cable faults before the cables are installed in walls. For PIM measurements, the PiMPro Tower passive intermodulation analyzers from CCI are available through Rohde&Schwarz.

For further information about our installation and maintenance solutions:

www.rohde-schwarz.com/solutions/test-and-measurement/mobile-network-testing/installation-and-maintenance/installation-and-maintenance_231988.html

7 ABBREVIATIONS

| Term | Explanation |
|-------|---|
| 5G NR | 5G New Radio |
| CW | Continuous wave |
| DAS | Distributed antenna system |
| DTF | Distance to fault |
| FBDA | Fiber bidirectional transceiver |
| KPI | Key performance indicator |
| LTE | Long Term Evolution |
| OBW | Occupied bandwidth |
| OSS | Operations support system |
| OTA | Over the air |
| PCI | Physical cell ID |
| PIM | Passive intermodulation |
| QoE | Quality of experience |
| RF | Radio frequency |
| RRU | Remote radio unit |
| RSRP | Reference signal receive power |
| SINR | Signal to interference plus noise ratio |
| SON | Self-organizing network |
| SSB | Synchronization signal blocks |
| TDD | Time division duplex |

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

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