

Keysight Technologies

5G Over-the-Air Performance Measurement and Evaluation Using FieldFox Handheld Analyzers

Application Note



Introduction

What is 5G anyway? Is it another new radio evolved from 4G LTE with higher speed? Why do we care so much about 5G given that some regions of the world just deployed their first LTE networks not long ago?

5G is not simply an iteration of 4G. It is truly revolutionary and is going to change everything we have grown accustomed to.

Over the past 30 years, we've sailed through 1G (1980s, AMPS/ETACS) mobile network, which brought analog voice to the masses. With the advancement of integrated circuit and digital signal processing, 2G (1990s, GSM/CDMA) made digital voice available and increased network capacity dramatically. 3G (2000s, WCDMA/EVDO) combined mobile data with voice, and first time customers could make a voice call while replying to email. 4G (2010s, LTE) was all about wireless internet (mobile IP) at higher speed, and desktop applications finally arrived on smartphones.

Nevertheless, the communications industry and customers are still segmented. We have wireline/internet providers, cable TV and internet service providers, wireless operators, over-the-top application providers, etc. Consumers and businesses get connections from various operators and on different platforms that often don't even talk to each other. There is significant overhead in the networks, and they must allocate substantial resources just to manage these overheads (e.g., signaling, billing, device management).

From the perspective of the end user, 5G is a connected application ecosystem. Each application will adaptively manage data speed, latency and reliability based on the tasks required. For example, for an autopiloted car, which requires very reliable, instant response and a secure link at highway speeds, a 5G network will provide wide coverage, small latency, and an encrypted communication link instead of blindly assigning a 100-MHz channel for the car, because higher throughput is not equal to short latency and reliable coverage.

From the perspective of service providers, 5G will consolidate all its communication systems under one roof to meet end-user application needs, such as data, voice, video, internet of things and crucial communications. 5G will provide much higher throughput, ultra-low latency, dramatically increased network capacity, reliability and secure services.

So, what are the 5G benchmarks? In general, 5G network architecture should provide:

- Massive capacity: 1000 times more than 4G
- Super-fast data rate: 100 times more than 4G
- Ultra-low latency: < 1ms

To achieve these goals, network and user equipment manufacturers must invent new technologies to make the network drastically more efficient and deploy a new spectrum to support much wider bandwidth requirements.

There are three key technologies that 5G needs: millimeter-wave (mm-Wave) network deployment, massive MIMO, and beamforming.

5G presents uncharted territory for RF engineers. How to characterize mm-Wave air interface? How to measure antenna efficiency? What are the potential interference issues in 5G networks? What solutions can address 5G over-the-air (OTA) measurements to help evaluate 5G trial networks?

Millimeter-Wave Band for 5G Deployment

LTE with 20 MHz bandwidth and 64QAM can achieve 100 Mbps data rate on the downlink, but for 5G to provide 100x higher data rates, it will require much wider bandwidth standards. The current sub 3 GHz cellular band won't be able to support wider bandwidths. Therefore, the only way to make 5G work is to move the system to a higher frequency band.

5G requires much higher bandwidth, as much as 800 MHz to 2 GHz. The frequency bands that have such potential are millimeter-wave bands. As we recalled when satellite communication started to deploy Ka-band (26.5 GHz to 40 GHz), it increased channel bandwidth from a typical bandwidth of 54 MHz to 500 MHz through 2 GHz, accompanied with spot beam frequency reuse. It can achieve Gigabit IP connection. Therefore, 5G will need to do the same thing.

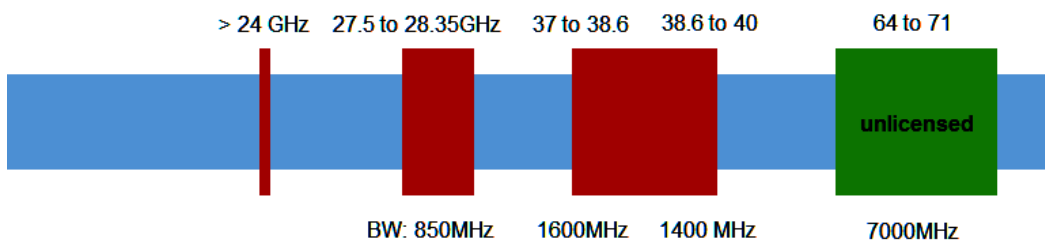


Figure 1. FCC 5G Frontier bands

In October 2015, the FCC allocated three mmWave bands for 5G services; these bands are called frontier spectrum for 5G services. There is more spectrum under investigation above 24 GHz.

The 28 GHz band supports 850 MHz of bandwidth; the 37-40 GHz band supports 3 GHz of bandwidth; and a whopping 7 GHz of bandwidth is supported on 64-71 GHz in an unlicensed band. These allocations of spectrum and bandwidth make the 5G service possible.

Millimeter-Wave Link Propagation and Link Budget

Commercial wireless service frequencies are below 6 GHz including Wi-Fi. The channel characteristics of these bands are well understood with many design tools available to use. But deploying mmWave frequency bands to provide a link between UE and base station (BS) presents many technical challenges. One of the first things to understand is mm-wave path loss properties, and build a predictable mathematical model.

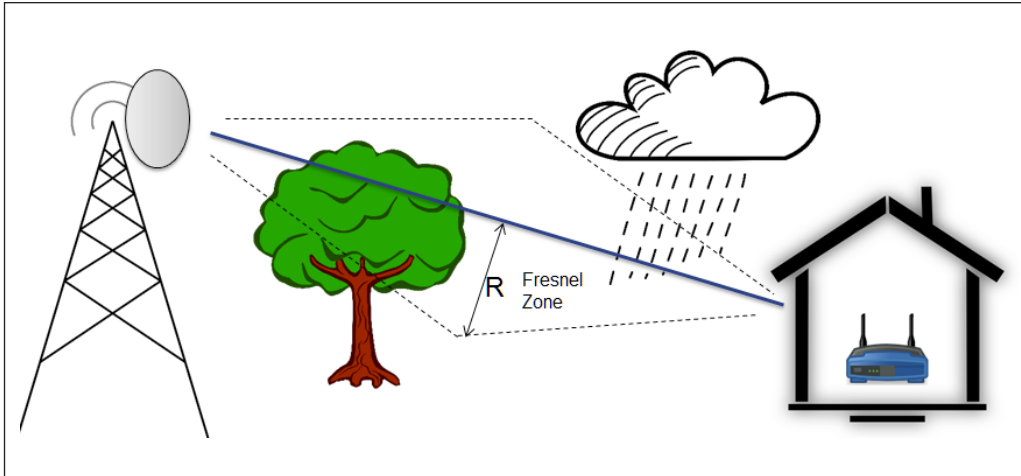


Figure 2. Various factors affect 5G radio received signal level

To investigate 5G link behaviors, path loss and link budget are two essential elements.

5G link includes Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) components in the radio propagation environment. LOS is close (but not exact at above 60 GHz) to free space path loss, whereas NLOS path loss deviates significantly from free space. The typical process is to make a propagation loss measurement at a specific frequency and terrain, and then do a curve fitting to find the loss of exponent n . The combined path loss is proportional to $(\text{distance between transmit and receive antenna})^n$, where n is the loss of exponent, which can range from 2 to 4.

$$\text{Free space path loss} = (4\pi d/\lambda)^2 \quad (d: \text{distance}; \lambda: \text{wavelength})$$

$$\text{Free space path loss in dB} = 92.45 + 20 \log(\text{distance in km}) + 20 \log(\text{frequency in GHz})$$

Point-to-point microwave communications requires a clearance between the propagation path and the nearest obstacles on the ground, which is governed by Fresnel zone theory. If the zone is 60% clear, it is LOS propagation. 5G networks, however, will have much lower antenna height, which could potentially introduce significant propagation blockage.

5G mmWave link budget is quite different from traditional sub 6 GHz wireless link budget and can cause extra losses due to rain fade, shadowing loss, foliage, atmosphere absorption, humidity, and Fresnel blockage.

Below is an example calculation of 5G link budget, which, depending on the band and type of cell, could vary.

*Received power in dBm = Tx power + Tx antenna gain + Rx antenna gain – path loss
 – rain fade (est. 2 dB/200m) – shadowing loss (20 to 30 dB)– foliage loss (10 to 50 dB)
 – atmosphere absorption – terrain /humility – Fresnel blockage – system margin*

Fresnel zone radius (R) = $17.32 \times \sqrt{(d/4f)}$ (d in km, f in GHz)

By examining the above equations, it is obvious that many factors can cripple mm-Wave links. Link budget is the most important area of focus for any 5G deployment team.

Propagation loss measurements with FieldFox

Keysight's FieldFox handheld microwave analyzer has an operating mode called extended range transmission analysis (ERTA). ERTA requires a connection between two FieldFox instruments – with one acting as the transmitter and the other as the receiver. Triggers on each box synchronize the measurement. Ethernet connection is used to set frequency range and transfer the results from transmitter to receiver, where the receiver is always the master in this setup. The splitter at transmitter side is used to measure output power from transmitter, so that the receiver side knows the exact power level being transmitted. The real-time data can be recorded, played back and exported for post analysis.

If longer distances are required for the measurement and physical cable connections are no longer viable, then an external laptop can be used to control both FieldFox instruments and implement a software trigger to perform the ERTA measurement at reduced speed.

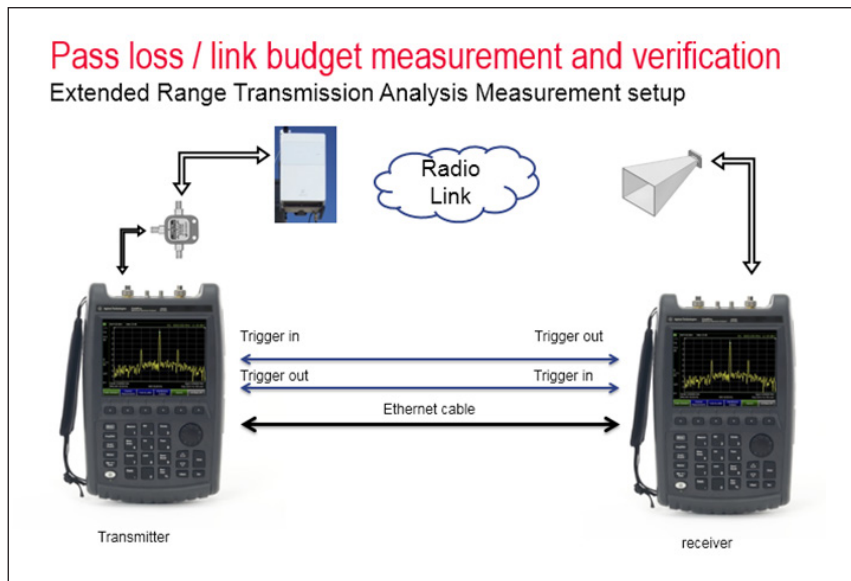


Figure 3. ERTA setup for propagation loss measurement

Massive MIMO

Massive MIMO is extension of multi-user MIMO, the number of base station antennas is much larger than the number of UEs in the cell. The typical number of antennas is about 48 to 64. The increase in the number of antennas makes the beam much narrower, which allows the base station to deliver RF energy to the UE more precisely and efficiently.

Each antenna's phase and gain can be controlled individually; channel information is kept with BS. This implementation simplifies UE design without adding multiple receiver antennas.

Installation of a large number of BS antennas will increase SNR in the cell, which leads to higher cell site capacity and throughput. As 5G massive MIMO implementation is on mm-Wave, the physical size of the antenna is quite small and is easy to install and maintain.

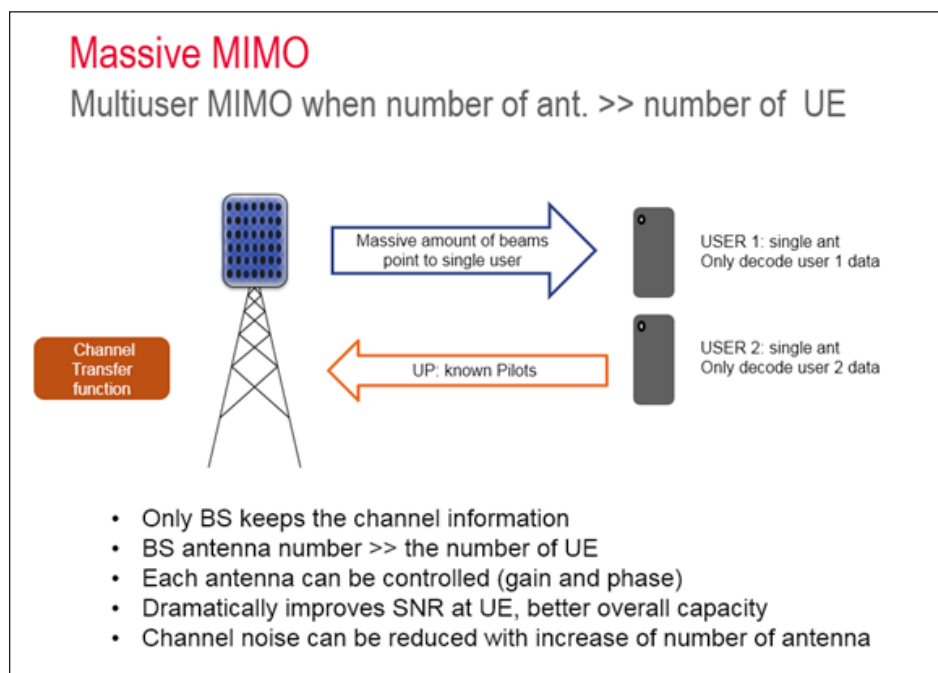


Figure 4. Massive MIMO operation principle

Beamforming

When each element of a phased array antenna can be controlled, beamforming can be implemented to achieve much better efficiency to overcome path loss, channel noise and channel cross talks. At millimeter band, the path loss is much bigger than sub 6 GHz channel, beamforming is crucial to the success of 5G network.

Figure 5 shows how beamforming works. On the left side, the delay between two phased elements is 0. The wave travels straight. Adding delay, the wave will change direction. When the delay of a phased array antenna's element can be controlled individually, BS can steer multiple beams to multiple UEs at same time.

5G beamforming has three stages: beam acquisition, feedback and change. In beam acquisition phase, BS does a beam sweep, sends out a beam to eight different directions in one symbol, UE detects the best beam, and transmits RACH to BS. In feedback and change stages, UE sends the ranking list of beams to BS, the best possible beam will be steered towards the UE. Lastly, during data transfer, UE can constantly provide feedback to BS to make small adjustments of the beam to achieve better signal-to-noise ratio.

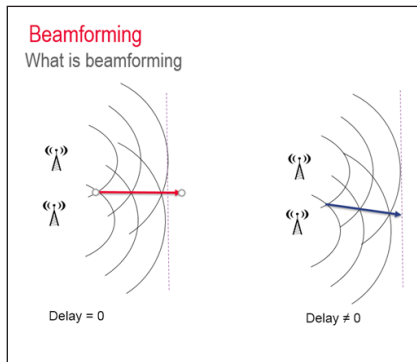


Figure 5. How beamforming works

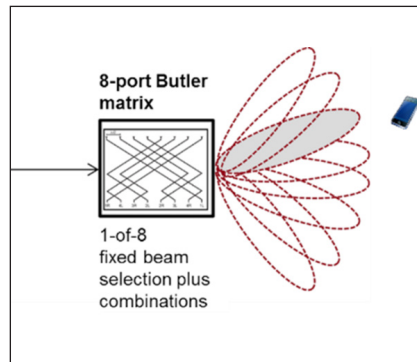


Figure 6. 5G beam acquisition and feedback

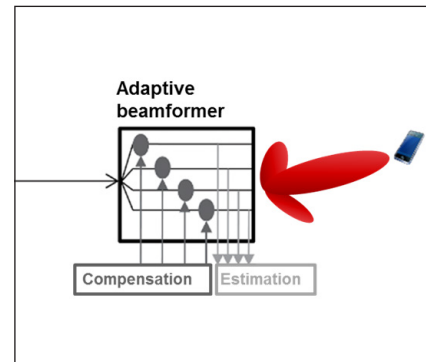


Figure 7. 5G beam change.

Phased array antenna pattern and phase delay test

Because 5G base station radio and its phased array antenna are integrated into a single hardware unit, there is no RF connector at antenna to allow test equipment to measure return loss and VSWR. However, it's necessary to know the performance of the antenna.

Antenna beam width from a mmWave phased array antenna is very narrow, which means its energy can be steered towards an over-the-air coupling probe, in this case a horn antenna. The spectrum analyzer measures the antenna pattern of the array and the isolation between the main lobe and side lobe.

Figure 8 shows how the spectrum analyzer can be configured to verify antenna pattern. The spectrum analyzer is configured as zero span. Set sweep time long enough to synchronize to the rotation of the golden antenna.

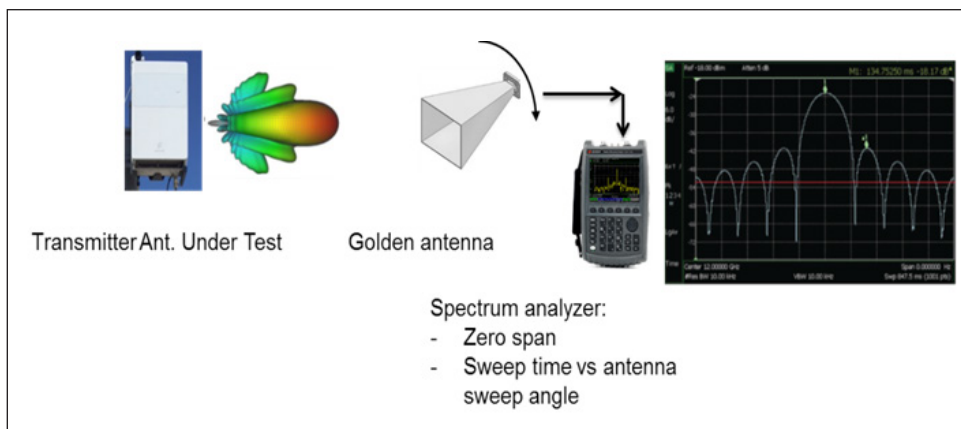


Figure 8. Antenna pattern verification using a FieldFox spectrum analyzer

In addition, a 5G phased array antenna has up to 64 elements. Each element's phase can be adjusted, and it is very important to know whether the adjustment can be translated into phase shift over the air.

A network analyzer with a vector volt meter (VVM) measures the phase shift between two receiving ports. Pick one of the elements as reference, and connect it to port 1, that connection can be via an antenna probe. Port 2 can be attached to the element under test. The VVM reports the delta phase and magnitude between the two elements. The delta phase is the phase adjustment of the phased array antenna.

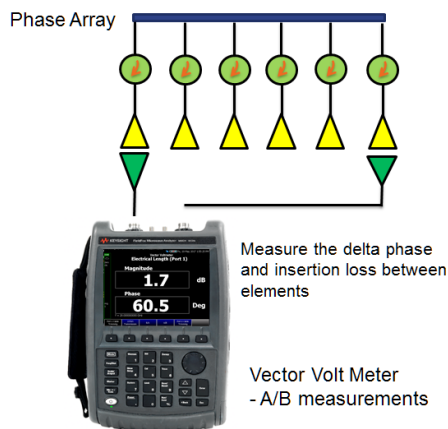


Figure 9. Using a VVM to characterize phased array antenna

FieldFox microwave analyzer helps to speed up 5G pre-deployment

The FieldFox microwave analyzer integrates many key mmWave tests into one package to help 5G pre-deployment tests and on-going maintenance. Since 5G is still in development stage, it will change along with standardization development, therefore new tests will be added. FieldFox is a software-defined instrument, except for frequency, all measurement capabilities are enabled via software licenses.

In 5G pre-deployment stage, FieldFox can perform many essential tests:

- Frequency coverage: 9 kHz to 32/44/50 GHz
- Spectrum analysis
- Interference analyzer with record and playback
- Built-in millimeter wave continuous wave independent source
- Real-time spectrum analyzer with record and playback
- Channel scanner with google map file format (CSV/KML) support
- Built-in power meter
- Extended range transmission analysis
- Vector voltmeter
- Cable and antenna analyzer
- Vector network analyzer

In addition, FieldFox is ruggedly designed and battery powered. It has no fans or vents and can operate from - 10°C to + 55°C and meet the IP53 standard.

Summary

Deploying 5G on mmWave presents great challenges to RF engineers. It is essential to have a robust channel model for 5G mmWave frequencies. Massive MIMO and beamforming are an integral part of 5G, and early extensive tests are required to make them deployable.

Keysight's FieldFox analyzer provides propagation loss test, antenna pattern over-the-air test, phased array antenna verification and many other common mm-Wave tests in a single instrument. It greatly improves the efficiency in 5G pre-deployment, first-office applications and on-going maintenance.

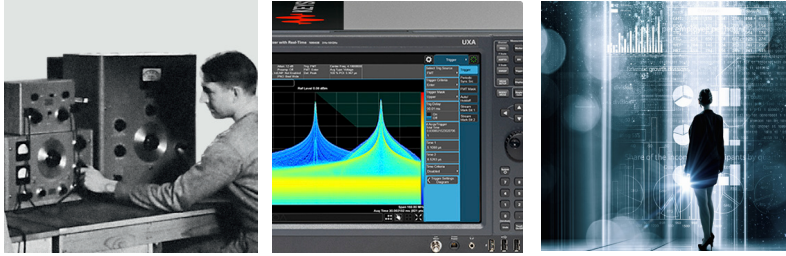


Figure 10. FieldFox microwave analyzer

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