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Research Article

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Solving 5G Antenna Design Issues

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Abstract As the cellular phone industry continues to advance to meet demands for higher data rates, lower latency, and greater reliability, RF system design has once again become the bottleneck for any cellular device or network aiming to deliver more data to more users to deliver more sophisticated use cases.

Keywords RF, 5G, antenna, mimo.

1. Introduction

As the 3rd Generation Partnership Project (3GPP) continues to release more specifications to respond to new requirements and push the industry further into the 5G area, confusion and misunderstandings are also emerging, leaving OEMs questioning their plans to roll out their 5G -Give Next Generation Products.

The antenna design is by far the most confusing part of this process as it depends almost entirely on the final device form factor and OEM preferences. In this manuscript, we give an overview of the antenna design of 5G user equipment (UE).

2. Materials and methods:

2.1 The new features of 5G and their differences compared to the current 4G LTE

To understand why 5G is capable of delivering much higher data rates than current 4G technology, it may help to first look at the Shannon-Hartley theorem:

C = MxB log2(1 + S/N)

- C is the channel capacity in bit/second
- M is the number of channels
- B is the bandwidth of each channel
- S/N is the signal to noise ratio

This is actually a conjecture based on the theorem that in order to have higher channel capacity improvements must be made to match the M, B and S/N system. 5G, evolving from 4G, implements in its architecture some well-known and long-established techniques to improve channel capacity:

- Carrier Aggregation (CA) > Increased Bandwidth (B)
- MIMO (Multiple-in-Multiple-out) architecture > Increase in count of channels (M)
- Allocation of new frequency bands > Increase in bandwidth (B)
- Adaptive adoption of higher-order modulation schemes > S/N and B

Compared to 4G, 5G brings the same techniques to the next level of performance and complexity. This inevitably takes antenna design for 5G devices to the next level to meet ever-increasing demands for greater bandwidth, more frequency bands and better interference immunity.

Other differences are:

- Speed is one of the key differences between 4G and 5G, meaning applications that require faster response times will reap tremendous benefits from migrating to 5G technology.
- Another key difference is the reduction in latency, which enables features like remote control of machines with augmented reality and full 4K video streaming. In turn, these capabilities will enable a wide range of new applications in enterprise, transportation, medical, retail, managed home office, manufacturing and other business cases.
- Finally, 5G promises a higher level of security. The goal is to enable safer business and financial transactions and better cyber defenses for 5G devices.
- 5G is expected to become the dominant network technology by the end of 2027. Meanwhile, 4G LTE networks have a long life ahead of them, so you have several options when it comes to network technology. For one thing, if 4G LTE meets your performance and throughput requirements, you might be able to stay the course for the foreseeable future. However, there is also a strong case for a future-proof deployment with 5G devices – which include a 4G fallback feature – in order to take advantage of 5G capabilities when the network building process is complete.

2.2 Tuned Antenna System

Due to strict size limitations, modern wireless devices typically use active antenna tuners as an efficient way to reduce antenna size. It can intelligently adjust the antenna according to the changing operating environment, frequency band and bandwidth coverage. With potentially higher AC order in 5G and additional cellular bands, the antenna tuning system must be able to support more tuner states as well as a larger frequency bandwidth per tuner state.

2.3 New frequency bands

According to 3GPP version 15, two basic frequency ranges (FR1 and FR2) must be used for 5G:

FR1: 410MHz to 7.125GHz;

FR2: 24.25 to 52.6GHz

In the FR1 standard, 5G adopts the 3.3 ~ 3.8, 3.8 ~ 4.2, and 4.4 ~ 4.9 GHz bands in addition to the existing sub-3GHz bands in 4G LTE. This leads to new requirements for cellular antennas to provide additional frequency coverages in the sub-6GHz frequency range

Table 1: Operating bands of the new 5G radio (NR) in FR1

NR Operating Band	Uplink(UL) operating band BS recevie UE transmit		Downlink(DL) operating band BS transmit UE receive		
	$F_{UL\_low} – F_{UL\_high}$	Total BW	$F_{DL\_low} – FD_{DL\_high}$	Total BW	
n1	1920 MHz-1980 MHz	60	2110 MHz-2170 MHz	60	FDD
n2	1850 MHz-1910 MHz	60	1930 MHz-1990 MHz	60	FDD
n3	1710 MHz-1785MHz	75	1805 MHz-1880 MHz	75	FDD
n5	824 MHz-849 MHz	25	869 MHz-894 MHz	25	FDD
n7	2500 MHz-2570 MHz	70	2620 MHz-2690 MHz	70	FDD
n8	880 MHz-915 MHz	35	925 MHz-960 MHz	35	FDD
n20	832 MHz-862 MHz	30	791 MHz-821 MHz	30	FDD
n28	703 MHz-748 MHz	45	758 MHz-803 MHz	45	FDD
n38	2570 MHz-2620 MHz	50	2570 MHz-2620 MHz	50	TDD
n41	2496 MHz-2690 MHz	194	2496 MHz-2690 MHz	194	TDD
n50	1432 MHz-1517 MHz	85	1432 MHz-1517 MHz	85	TDD
n51	1427 MHz-1432 MHz	5	1427 MHz-1432 MHz	5	TDD
n66	1710 MHz-1780 MHz	70	2110 MHz-2200 MHz	90	FDD
n70	1695 MHz-1710MHz	15	1995 MHz-2020 MHz	25	FDD
n71	663 MHz-698 MHz	35	617 MHz-652 MHz	35	FDD

n74	1427 MHz-1432 MHz	43	1475 MHz-1518 MHz	43	FDD
n75	N/A		1432 MHz-1517 MHz	85	SDL
n76	N/A		1427 MHz-1432 MHz	5	SDL
n78	3300 MHz-3800 MHz	500	3300 MHz-3800 MHz	500	TDD
n77	3300 MHz-4200 MHz	900	3300 MHz-4200 MHz	900	TDD
n79	4400 MHz-5000 MHz	600	4400 MHz-5000 MHz	600	TDD
n80	1710 MHz-1785 MHz	75	N/A		SUL
n81	880 MHz-915 MHz	35	N/A		SUL
n82	832 MHz-862 MHz	30	N/A		SUL
n83	703 MHz-748 MHz	45	N/A		SUL
n84	1920 MHz-1980 MHz	60	N/A		SUL
n86	1710 MHz-1780 MHz	70	N/A		SUL

FR2 or the mmWave frequency range offers an extremely wide bandwidth, up to 2 GHz in some ranges. Devices or systems that want to use this large bandwidth require fundamentally different antenna designs. Because signal path loss is inversely proportional to signal wavelength, millimeter wave signals experience significant path loss.
To compensate for these losses, increasing antenna gain through the development of phased array antennas is becoming a reliable, industry-recognized solution. Phased array antenna design opens up a whole new area of antenna design that doesn't exist in 4G.

Table 2: Operating bands of the new 5G radio (NR) in FR2

NR Operating Band	**Uplink(UL) operating band**		**Downlink(DL) operating band**		**Duplex Mode**
	BS Recieve UE Transmit		**BS Transmit UE Receive**		
	$F_{UL\_low} – F_{UL\ high}$	**Total BW**	$F_{UL\_low} – F_{UL\_high}$	**Total BW**	
N257	26500 MHz-29500 MHz	3000	26500 MHz-29500 MHz	3000	TDD
N258	24250 MHz-27500 MHz	3260	24250 MHz-27500 MHz	3260	TDD
N260	37000 MHz-40000 MHz	3000	37000 MHz-40000 MHz	3000	TDD
N261	27500 MHz-28350 MHz	850	27500 MHz-28350 MHz	850	TDD

2.4 MIMO adaptive antennas

The "massive MIMO" (Multiple Input Multiple Output) smart antennas deployed as part of the arrival of 5G, are made up of multiple transmitters, integrated together in a single piece of equipment, and which, controlled by software, make it possible to focus the radio wave beam over a given area.
In other words, the latter will direct the signal of the mobile network towards the only people who need it, at a time T. The radio signal is therefore not directed everywhere and all the time continuously, but, as the antennas do previous generations, focuses only on the devices that demand it, when they need access to it.
This technique, known as focusing (also known as beamforming), makes it possible to increase the capacity of the mobile network thanks to a more efficient allocation of waves to the communications of each user connected to the cell.

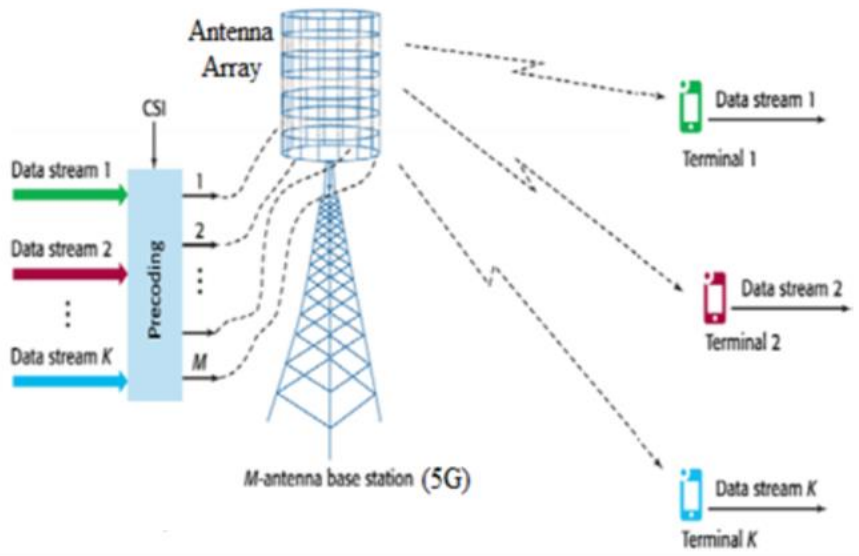

Figure 1: MIMO in 5G NR System

2.5 Beamforming:

Beamforming works on the same principle as the soundbar in your home theater in your living room: so that the signal is received where it is useful to the user and does not create noise for others elsewhere, a software drives a set of small transmitters so that their signals gather where needed, and cancel out elsewhere. This is the beam principle.

These signal beams are only emitted when a device (smartphone, tablet or laptop, etc.) needs to connect. The signal sent to the device is therefore personalized according to the needs of the user.

The advantage of this targeting of the 5G network per user is the energy gain. Indeed, thanks to the massive MIMO adaptive antennas and the beamforming, the energy is not wasted!

It is therefore a beneficial process in terms of the environment, since it avoids wasting signals, and therefore consumes less energy.

Light years away from the omnipresence of 4G, which has the characteristic of permanent ambient connectivity, this process is innovative because it is much more suited to the expectations of connected people. Its flexibility and precision make it the new star of 5G!

These new, more efficient antennas will eventually aggregate all frequency bands and replace existing 4G antennas.

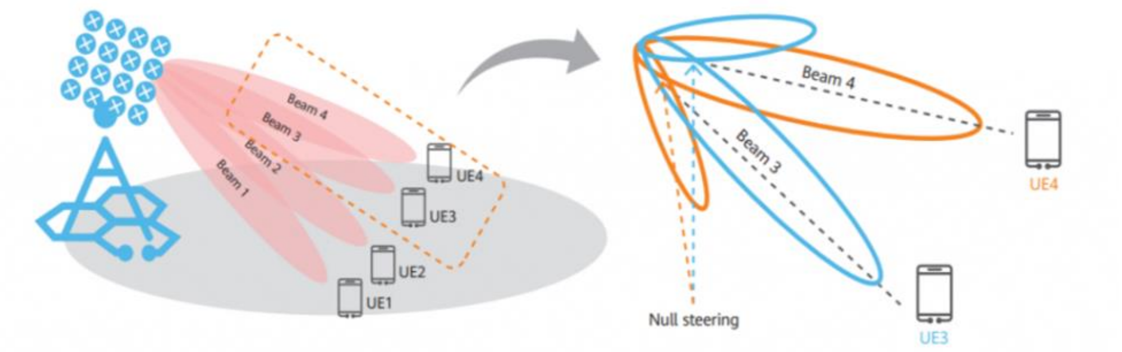

Figure 2: Beamforming in 5G NR System

2.6 Design of difficult antenna systems due to coexistence

In 5G, Massive-MIMO (mMIMO) will be a necessary component to take cell capacity and UE download throughput to the next level. While most mMIMO antenna specifications and technology analysis today focus on the base station, where 32 or more logical antenna ports are required, it is expected that the number of antennas on the EU is also increasing.

Additionally, due to the activation of multiple access technology in 5G, Bluetooth/WLAN, cellular, etc. are more often transmitted simultaneously on the UE, the problem of antenna coexistence can only be more complicated to solve. If not properly addressed, antenna coexistence issues can lead to reduced communication range, an unexpected blind spot, or even a sporadic drop in connectivity quality.

3. Results & Discussion

The result of our work has been presented below:

Antennas should be placed strategically in a 5G UE to take full advantage of MIMO technology.

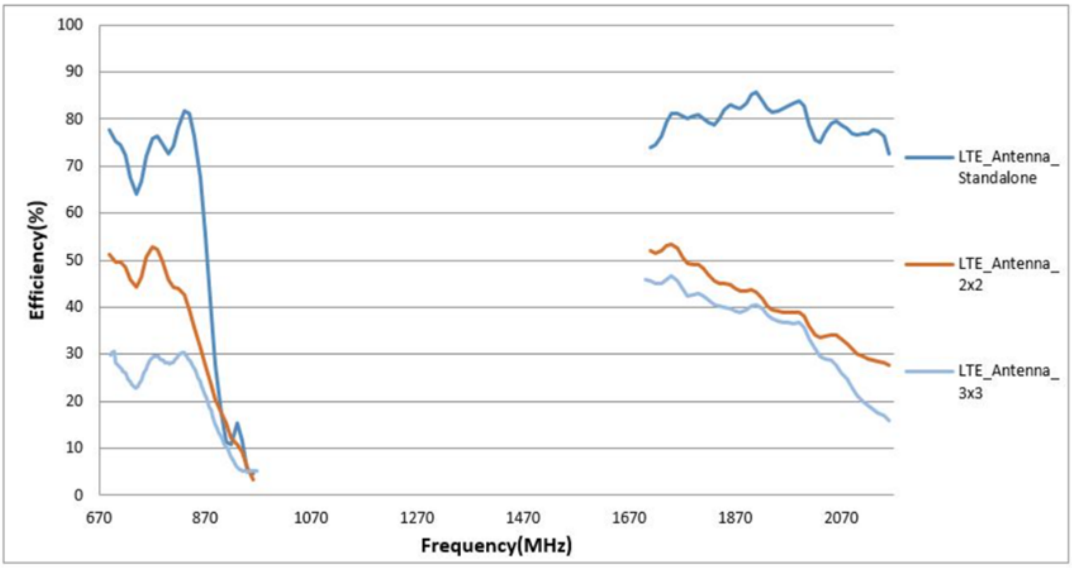

Figure 3: Reduced antenna efficiency when changing from a SISO system to a MIMO system

Let's discuss some design considerations that can help 5G succeed.

- **Design Approach for Sub-6GHz Antennas**
  5G antennas can be divided into two categories according to their operating frequency: Sub-6GHz and mmWave. Comparing 5G sub-6GHz with 4G LTE, the design concepts of the system's antennas and RF front-end are very similar, the only difference being the lateral complexity. This means that when moving from 4G to 5G in the sub-6GHz range on the system side, the same components are used and the antenna is still a standalone omnidirectional antenna (as opposed to a network antenna).
  In this frequency range, the most common antenna types such as dipole antennas, monopole antennas, PIFA antennas, IFA antennas, loop antennas etc. will always play a major role, as was the case with 2G/3G/4G networks. Antenna form factors can vary from a simple printed circuit board antenna to a complex LDS (laser direct patterning) antenna.
- The conflict between device downsizing requirements and increasing antenna bandwidth will remain the main challenge, but it will be much more difficult than before. A viable solution to this increasingly intense confrontation is to design an active antenna system.
  The most common active antenna systems can be divided into two categories: active impedance matching and antenna aperture tuning.
  The active impedance matching technique allows the antenna system to choose among different impedance matching networks based on changes in operating conditions, while the active aperture tuning directly changes the characteristics intrinsic to the antenna.

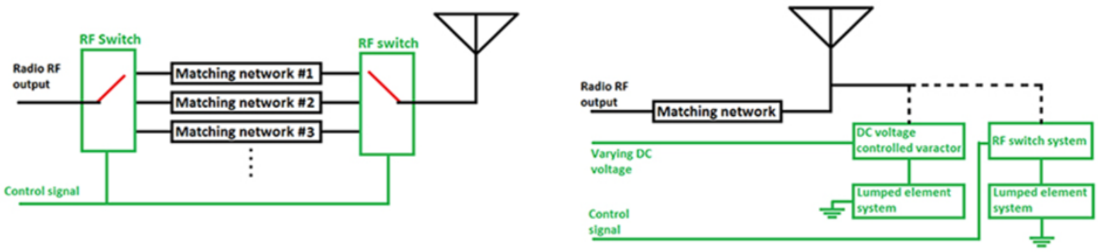

Figure 4: Active matching diagram (left) and active opening chord diagram (right)

OEMs can also use standard antennas (OTS) to simplify the antenna design process. However, as with 4G, the same OTS antenna behaves differently when placed in different devices, as different circuit boards provide different RF reference, even if the antennas themselves are identical. OEMs should at least assume that they have custom antenna matching networks for all selected OTA antennas

- **Approach to millimeter wave antenna design**
  On mmWave frequencies, several signal propagation losses severely limit cell size and the bandwidth advantage can be heavily masked by connectivity coverage issues. To compensate for signal attenuation, phased array antennas become necessary due to their ability to achieve very high gain (dBi).

4. Key Contributions

- Performance evaluation,
- Cellular system functional, logical and physical architecture
- Radio access network,
- Security,
- Technology development and readiness,
- Business validation and innovation,
- Contribution to standardization, open source and communities

5. Conclusion:

Designing a phased array antenna for 5G mmWave requires much deeper initial knowledge of fundamental antenna design concepts, array antenna design practices, mmWave signal propagation behavior, and even more. At a minimum, a phased array antenna must be able to steer and optimize the radiation beam to maximize EIRP (dBm) to a mobile receiving device within its cellular sector. A well-designed phased array antenna for 5G must also consider dual polarization, reduced array size, side-lobe level attenuation, improved range and beam steering angle resolution, system noise suppression, energy efficiency improvement, etc

Testing millimeter wave antennas also presents technical difficulties. Calibration and configuration at these high frequencies, where losses in configuration are more pronounced than at 4G frequencies, is even more complex. According to conservative estimates, equipment for these tests may require investments of more than a million dollars. Choosing a test partner who understands the specifications and procedures therefore becomes crucial.

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