5G MIMO OTA Testing on Frequency Range 2 (FR2)

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Abstract

5G MIMO OTA (Multiple Input Multiple Output Over the Air) testing challenges and 28 GHz solution are presented. The paper highlights the reasons a new approach in MIMO OTA testing is needed. This work describes 5G channel modelling based on four selected channel models, shows that 75 cm range length is sufficient to support a standard handheld device, and 3 probes per channel model are needed to sufficiently emulate the desired figure of merit in a FR2 MIMO OTA setup.

1 Introduction

Recent advancements in wireless communication systems have led to 5G radio system development. The target of 5G has been to provide higher data rates, ultra-low latency and reliable communications [1]. In 3GPP, high data rate communications have the priority.

It is well known that a high data rate can be achieved using MIMO, higher bandwidth or smaller cells. Bandwidth is very difficult to increase in the existing licensed bands. Therefore, new bands have been identified from so-called FR2 (Frequency Range 2). These frequencies start from 24.25 GHz (Band n258) and span up to 40 GHz (Band n261). Deployments of FR2 are expected to be extended to higher ranges, e.g., 66 GHz to 71 GHz [11].

FR2 allows the use of higher bandwidths (up to 3.25 GHz at band n258) and physically smaller antennas, which enable the use of beamforming arrays in the UE. The penalty for using these higher frequency bands is very high path loss, leading to reduced range, i.e., limitations in coverage of the radio links. Therfore, beamforming becomes mandatory in the UE as the limited link budget would require very high transmitter power at the gNb (generalized Node B), and thus it is not a very economical solution. This also means that the fundamental KPIs (Key Performance Indicators) are different in 5G NR FR2 than those in 4G or 5G NR FR1.

2 Selecting the Correct KPIs

When applying a beamformer to the gNb and/or UE, the number of antenna ports becomes large. Thus, it is impractical to test the wireless equipment in conductive mode and therefore OTA (Over the air) testing is preferred. Also, adding a connector to the wireless equipment seems impossible as the interface between baseband and RF is vanishing. This applies particularly to FR2 frequencies between 24.25 GHz and 40 GHz.

In LTE, MIMO OTA tests were introduced [9]. The Figure of Merit was spatial correlation, as it defines MIMO performance. Spatial correlation is a function of angular spread and antenna array element orientation and separation.

4G MIMO OTA testing is done in a standard size anechoic chamber, typically 3m by 3m. An FR2 chamber becomes a lot smaller due to shorter wavelength and presumably smaller array size.

An important design criteria of the system is that discretised spatial correlation can only follow the theoretical curve up to a certain point in array size, typically a few wavelengths [2], [3]. In Figure 1, the alignment is up to 1.8λ, yielding a 1.93 cm DUT size at 28 GHz. The above results correspond to uniformly spaced probes in a 2D ring. Note, a 'black box' approach is assumed, where DUT size equals array size. This approach would require up to ten-fold the number of probe antennas to support a reasonable size DUT (20 cm diameter) in FR2 and therefore becomes prohibitive in terms of cost and complexity. Thus, an alternate figure of merit must be introduced.

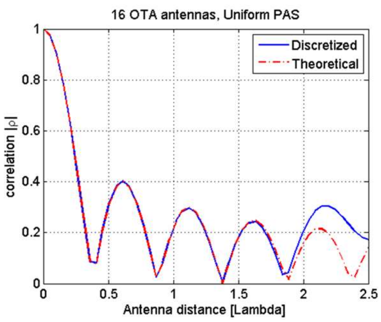

Figure 1. Spatial correlation in theory and discretized case with 16 OTA antennas, correlation behavior

In 3GPP, a lot of discussion has revolved around Power Angular Spectrum (PAS) Similarity Percentage (PSP) as a Figure of Merit in FR2 testing instead of spatial correlation [4]. As its name indicates, it expresses the beamformer's ability to estimate the appropriate Power Angular spread.

3 Test setup

This section covers a UE test method as discussed in 3GPP [5][6]. As discussed, the OTA system has radiator antennas that are specifically located to support the desired propagation environments.

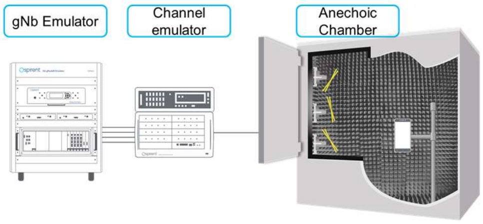

Figure 2. UE OTA test solution

The first consideration is the appropriate link budget. When generally considering OTA tests, it is assumed they are performed in the far field. Far field, as known, is defined by the antenna aperture size [8]. The UE is considered to be a "black box" UE, i.e., the array size becomes the UE size since the antenna locations on the device are unknown. Taking a realistic UE size (20 cm diameter), the far field criterion becomes as shown in Fig. 3.

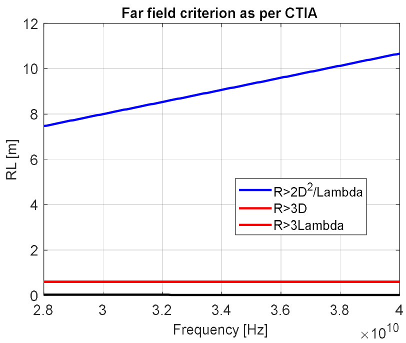

Figure 3. Far field as per CTIA requirements

Following the CTIA rule and taking the larger of the three criteria, we end up with a large chamber. Bearing in mind that path loss is already 79.44 dB at 28 GHz for an 8 meter distance, the test system becomes very difficult to design to compensate for air loss. It is desireable to have a smaller installation due to practical reasons (size, amplification stages, dynamic range) that can test beamforming in the UE as can be deployed in real life and be a differentiator in 5G. An 8-element beamformer response is depicted in figure 4.

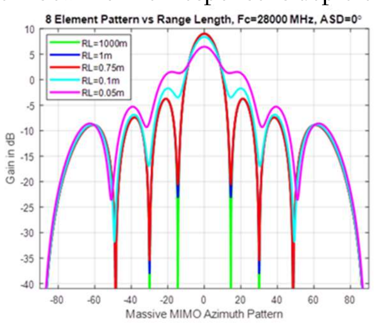

Figure 4. Beamformer response vs. range length

The 8-element beamformer does not suffer considerable change in beam response even if we are closer than 1m from the radiator. Furthermore, this assumption should hold for arrays with smaller dimensions and less resolution than this, where only a small difference in null depth can be observed between 1m and 0.75m of range length.

This leads to the conclusion that it is not necessary to have the UE in strictly far field as the fundamental characteristics do not suffer any considerable change even at short distances.

In Fig. 2., the probes in the chamber are selected based on the propagation environment. The overall framework for MIMO OTA channel modeling in FR2 is based on the 5G NR technical report TR 38.901 [7]. In the channel modeling for link level evaluation section of [7], five Cluster Delay Line (CDL) and Time Delay Line (TDL) channel tables are presented, namely CDL and TDL A…E. Since [7] covers frequency bands from 500MHz to 100GHz, it is natural to think that five CDLs cannot cover every possible scenario within that frequency range.

To alleviate that situation, [7] sees the tables as generalizations, and not as precise channel models like the ones defined in 4G LTE MIMO OTA [2]. Therefore, the CDLs and TDLs can be denormalized in delay and scaled in angle to represent virtually any desired scenario. For MIMO OTA 5G NR FR2, the denormalized and angle-scaled channel models are presented in [6]. For this paper, we only focus on CDL models, as they contain the spatial components of the propagation and are therefore more suitable to the MIMO OTA test solution. These models are downselected to CDL-A and CDL-C as per 3GPP recommendations.

The scaled and denormalized channel models are filtered by the gNB antenna, which is an 8x16 dual polarized patch array. The exact gNB assumptions, such as number of elements, layout, polarization, and codebooks, are given in [6]. Figure 5 illustrates the gNB array.

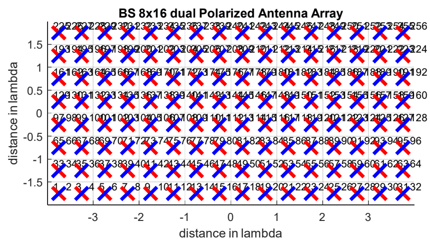

Figure 5. gNb antenna used in simulations

The UE, as mentioned before, utilizes a beamformer. In 3GPP, the evaluation of PSP typically utilizes a 4x4 planar array antenna for comparing probe layouts vs ideal channel models, thus for convenience, this antenna assumption is utilized for the UE in this paper.

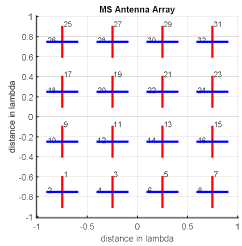

Figure 6. UE antenna used in simulations

The two antennas in Figures 5 and 6 will perform effective spatial filtering such that from the original 23-24 clusters only a few will be above a 30 dB threshold for the UMi scaled CDL-A channel model shown in Figure 7.

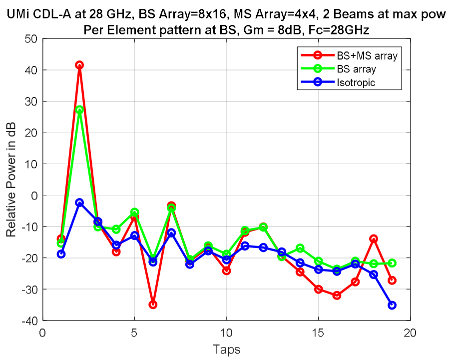

Figure 7. Clusters before and after spatial filtering, CDL-A UMi

The purpose of the MIMO OTA test system is to emulate the local environment at the DUT in the test volume of the anechoic chamber. This means that with the radiator antennas in Fig. 2, we have to emulate the environment expected for the given channel model so that the UE receives the expected signals. When the gNb performs the beamforming based on the antenna in Fig. 5, the number of clusters will be greatly reduced. The strongest two beams are selected at the gNB and are linearly combined in the plots shown below.

The beams are typically modelled as codebook angles of the antenna array (Fig. 6). Corresponding codebook angles for the gNB array are shown in Table 1, along with similarly quantized angles used at the UE for probe placement.

Table 1. *AoA, AoD, ZoA and ZoD of codebooks.*

Channel Model	Scaling	AoA B1	ZoA B1	AoD B1	ZoD B1	AoA B2	ZoA B2	AoD B2	ZoD B2
CDL-A	UMi	20	86.429	-4	100.71	20	93.571	-4	93.571
	InO	20	93.571	-4	93.571	20	86.429	-4	100.71
CDL-C	UMi	-20	72.143	-12	100.71	-12	72.143	-20	100.71
	InO	-12	65	4	100.71	12	72.143	4	93.571

The PAS seen by the 4x4 UE will resemble single or dual cluster models in the spatial domain, as shown in Fig.8.

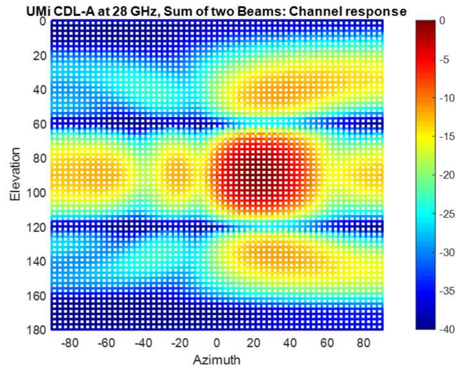

Figure 8. PAS seen by two beams

PSP calculated, as per [4], with antenna arrays in Fig. 5 and Fig. 6 are shown in Table 2 when calculated for the center of the test volume.

Table 2. *PSP vs. range length at the center of the test volume.*

RL	Channel Model	Scaling	PSP [%]
75 cm	CDL-A	UMi	89.19
		InO	90.25
	CDL-C	UMi	80.64
		InO	84.42
1 m	CDL-A	UMi	89.19
		InO	90.25
	CDL-C	UMi	80.64
		InO	84.42
1000 m	CDL-A	UMi	89.19
		InO	90.25
	CDL-C	UMi	80.63
		InO	84.42

We can see that the smallest PSP is obtained for the CDL-C model due to larger angular spread of the signal. The discussion of range length revolves around two options, 75 cm and 1 m. If the UE is in a fixed location in the center of the OTA antenna array, virtually no difference is observed and the PSP is the same with both range lengths. However, the difference of these range lengths can be seen when the UE is moved in offset from the original position, orthogonal to the boresight direction. Fig. 9 and Fig. 10 show the simulation results applying offset.

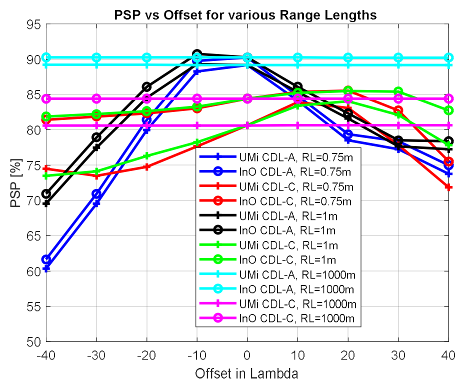

Figure 9. PSP vs. offset from the center point, range lengths 75 cm, 1 m and 1000 m

In Figure 9, we can see that the PSP is not symmetric around zero offset since PAS of the estimated channel model is not centered at boresight and varies between channel models.

The difference is seen only in the far edges of the domain simulations. When the range length is very long (1000 m), the PSP remains constant over all offset values since 1000 m is a far field assumption that equals 93333λ, wherein the offset of 40λ is relatively very small compared to this range length.

Equally, we can calculate the difference in PSP figures between 75 cm and 1 m range lengths, as in Figure 10.

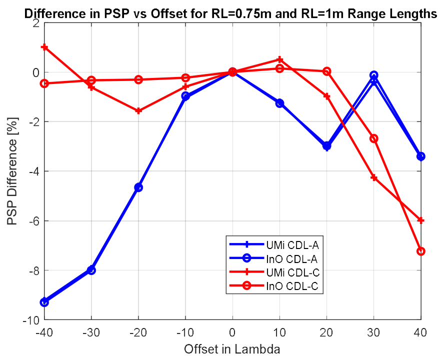

Figure 10. Difference between PSP at 75 cm and 1 m

The difference is greatest when the offset gets larger than 10λ in both directions. Even at ±20λ, the difference is less than 5%. At 28 GHz, wavelength equals 1.07 cm, thus -10λ to 10λ totals 21.43 cm, thus supporting a normal cell phone size test object. We can conclude that a chamber in FR2 produces a sufficient emulation of each of the channel models when the range length is 75 cm.

Probe count can be optimized as PSP improves when probe count per channel model is increased.

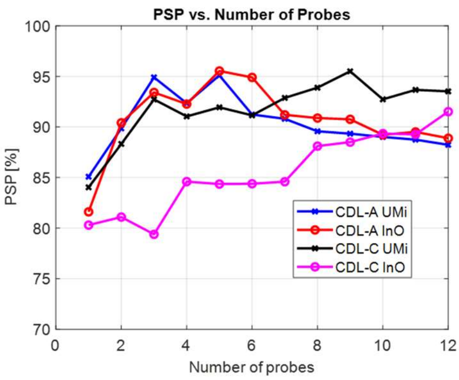

Figure 11. PSP vs. number of probes at RL=75 cm

Increasing probes from 1 to 3 per channel model produces the biggest gain in PSP. Thus, having 3 probes per channel model should be sufficient for practical purposes. We can see that increasing the number of probes will improve PSP, but the gain is very moderate compared to the gain realized by stepping up from 1 to 3.

6 Conclusions

This paper outlines some of important design topics of the FR2 MIMO OTA test solution. It shows that a range length of 75 cm is sufficient to support a 20 cm diameter device under test and the best performance improvement is when probe count is increased from 1 to 3 per channel model. These considerations are sufficient to define a test system for FR2 that measures PSP accurately.

8 References

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