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Impact of Effective Antenna Pattern on Radio Frequency Exposure Evaluation for 5G Base Station with Directional Antennas

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Abstract

Together with introduction of 5th generation (5G) of mobile communication system the new challenge for radio frequency (RF) exposure evaluation for base stations (BS) arises, which is mainly caused by high gain directional antennas with beamforming and beam steering. To assess RF exposure due to narrow and high gain service/traffic beams the extrapolation methods have been defined on the basis of exposure for broadcast/signaling beams which easier for determination due to theirs lower directivity. This paper indicates what is the impact on extrapolation of RF exposure for service/traffic beam if antenna gains assumed during calculations are based on nominal patterns, as measured in anechoic, instead of effective patterns determined by realistic propagation conditions. Example calculations performed for representative commercially available antenna indicate that extrapolated RF exposure for service/traffic beam can be overestimated by 1.5 dB to 2.0 dB, when power of reflected waves is dominant, i.e. BS and point of investigation are in non line of sight (NLOS) conditions.

1 Introduction

5th generation (5G) of mobile communication systems introduces wide use of high gain directional antenna by base stations (BS). On top of that the beamformed antenna pattern can be steered towards different directions inside the cell to maximize the end user data rate. Therefore, the radio frequency (RF) exposure evaluation is complex because the electromagnetic field exposure parameters may change rapidly depending on traffic variations and beam directions. The International Electrotechnical Commission (IEC) has proposed guidelines to address the actual parameters of RF exposure for massive multiple input multiple output (mMIMO) and beamforming in [1] and [2]. This paper investigates how the accuracy of extrapolation method proposed in [1] can be improved by using the effective antenna pattern instead of the nominal antenna pattern when assessing the EMF exposure levels in one place.
Section 2 of this paper clarifies the difference between nominal and effective antenna patterns. Section 3 indicates how the level of extrapolation factor changes upon replacement of the nominal antenna pattern by effective antenna pattern in the example of commercial antenna. Section 4 proposes closed-form model for calculation of effective antenna gain according to angular spread statistics in given propagation conditions. Section 5 summarizes and concludes the paper.

2 Nominal and effective antenna patterns

With increasing number of antenna elements in the array the *nominal* gain of the antenna array, as measured in anechoic chamber, increases and the half-power beam-width (HPBW) decreases. In scattering environment, the maximum realizable antenna array gain, the *effective* beam pattern and its associated HPBW differ from nominal values. Difference between the nominal and the effective patterns in the radio channel with scattering depends on the angular spread introduced by the real deployment scenarios.
Nominal antenna array gain in the free space propagation conditions can be expressed by following equation [3]:

$$g_{\max}^{Nom} = \frac{2}{B_{ho} \cdot B_{vo}} = N \cdot G_e \quad (1)$$

where $g_{\max}^{Nom}$ is the maximum nominal antenna array gain, B_{ho} and B_{vo} are the nominal root mean square (RMS) beamwidth in horizontal and vertical planes (in radians), respectively, N is the number of antenna elements in the array, and G_e is the gain of single antenna element. Equations (2)-(4) give the overview how the effective antenna patterns can be analytically obtained based on nominal antenna pattern and power angular spectrum (PAS) for assumed propagation environment model.

$$g^{Eff}(\phi_0,\theta_0) = \int_{-180^\circ}^{180^\circ}\int_{0^\circ}^{180^\circ} g^{Nom}(\phi,\theta)\cdot p(\phi-\phi_0,\theta-\theta_0)\,d\phi d\theta \quad (2)$$

$$g_{Az}^{Eff}(\phi_0) = g^{Eff}(\phi_0,\theta_0=90^\circ) = \int_{-180^\circ}^{180^\circ} g^{Nom}(\phi,\theta=90^\circ)\cdot p_{Az}(\phi-\phi_0)\,d\phi \quad (3)$$

$$g_{Ele}^{Eff}(\theta_0) = g^{Eff}(\phi_0=0^\circ,\theta_0) = \int_{0^\circ}^{180^\circ} g^{Nom}(\phi=0^\circ,\theta)\cdot p_{Ele}(\theta-\theta_0)\,d\theta \quad (4)$$

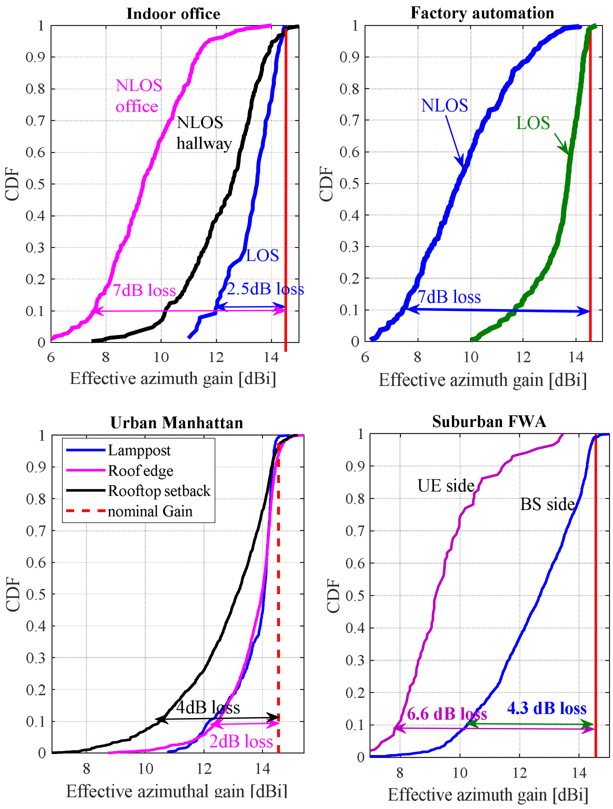

Figure 1. CDFs of effective antenna gains measured in indoor office, suburban FWA, factory automation and urban Manhattan environments presented in comparison with nominal antenna gain [4][5][6][7]

In above equations g^{Eff} indicates three-dimensional (3D) effective antenna pattern, whereas g^{Nom} indicates 3D nominal antenna pattern. g_{Az}^{Eff} and g_{Ele}^{Eff} indicate azimuth and elevation cuts of effective antenna pattern, ϕ and θ define angular domain in azimuth and elevation, respectively, whereas ϕ_0 and θ_0 indicate boresight direction between transmitter (Tx) and receiver (Rx) in azimuth and elevation, respectively. p_{Az} and p_{Ele} represent realizations of power angular spectrum (PAS) in azimuth and elevation.

Fig. 1 presents summary of statistically analyzed measurement result in different deployment scenarios, i.e. indoor office, suburban fixed wireless access (FWA), factory automation and urban Manhattan [4][5][6][7], in the form of cumulative distribution function (CDF) from measurement result samples. In all scenarios the severe impact of angular spread on effective antenna gain is visible. In case of NLOS the reduction in azimuth gain can be as high as 7 dB for 10% of measured radio links or 5 dB for 50% of measured radio links, in reference to maximum nominal gain of 14.5 dBi.

Measurement results demonstrate that nominal antenna patterns, as measured in anechoic chamber, are valid only in free space propagation conditions. This conclusion is particularly important in the context of calculations which are aimed to evaluate RF exposure from mMIMO antennas of 5G system.

3 Accuracy of extrapolation factor

To illustrate the impact of angular spread in real propagation conditions on antenna pattern and therefore on extrapolation factor defined in [1], the example of commercial antenna have been used [8]. Main parameters of antenna [8] are disclosed in Table 1. The effective antenna patterns for broadcast beams (also called signaling beams) and service beams (also called traffic beams) have been determined in statistical simulations according to (3) and (4). Simulations have been performed for 3.5 GHz frequency and the angular spread statistics from urban macro (UMa) channel model defined by 3rd generation partnership project (3GPP) standardization organization in [9]. Output effective beam patterns in horizontal plane are presented in Fig. 2, whereas Fig. 3 illustrates magnified view of main lobes. As can be noticed, the difference between maximum gains of nominal and effective beam patterns are small in case of line of sight (LOS) and for both broadcast/signaling and service/traffic beam are around 0.4 dB. However, this difference grows significantly in NLOS conditions, up to 4.8 dB and 6.3 dB for broadcast/signaling and service/service beams, respectively. Simulated values of maximum antenna gains are captured in Table 2.

According to definition made in [1] the extrapolation factor is the ratio of the equivalent isotropic radiated power (EIRP) envelope of all service/traffic beams to the EIRP envelope of the broadcast/signaling beam in the direction of the measurement location. Envelope of EIRP is determined by the maximum antenna gains in the full steering range of mMIMO antenna and the transmit power. Assuming the same transmit power is used for broadcast/signaling and service/traffic beams, the extrapolation factor in the boresight direction can be approximated based on maximum antenna gains of broadcast/signaling and service/traffic beams. Values of extrapolation factor calculated according to this approach for nominal and effective maximum antenna gains are captured in Table 2. Results indicate that for the analyzed example of commercial antenna and assumed propagation environment the extrapolation factor can be overestimated by 1.5 dB in NLOS conditions, which may lead to overly conservative compliance distance due to RF exposure.

Table 1. Main parameters of assumed antenna patterns [8]

Parameter	**Beam**
Broadcast/signaling	
Gain [dBi]	20.8
Horizontal HPBW [°]	58
Vertical HPBW [°]	6.6
Service/traffic	
Gain [dBi]	16.7
Horizontal HPBW [°]	24
Vertical HPBW [°]	6.6

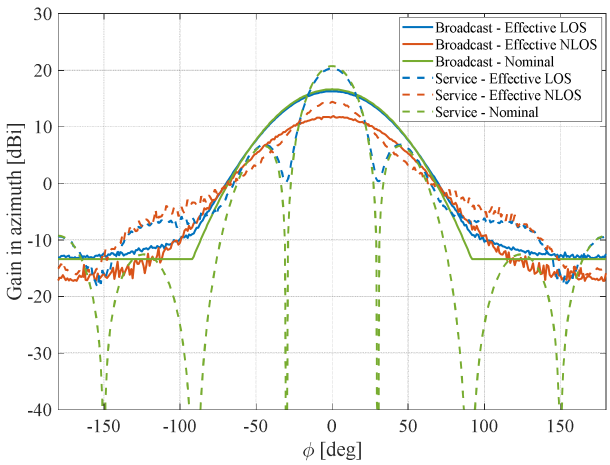

Figure 2. Nominal and effective antenna patterns of broadcast/signaling and service/traffice beams [8]

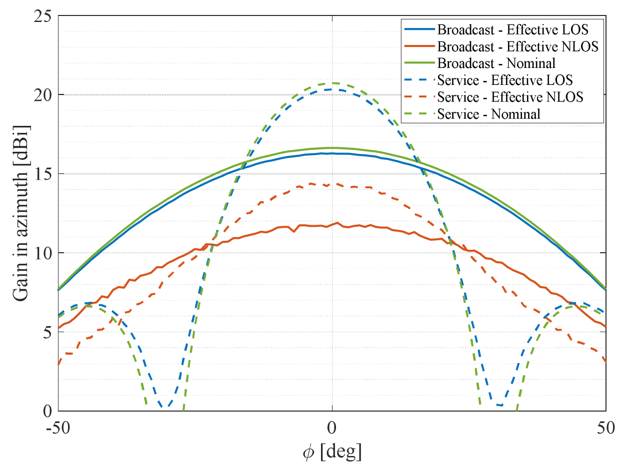

Figure 3. Nominal and effective antenna patterns of broadcast and service/traffice beams [8] – magnified view of main lobes

Table 2. Maximum antenna gains and approximated extrapolation factor according to statistical simulations

Beam type	Nominal max gain [dBi]	Simulated effective max gain [dBi]	
		LOS	*NLOS*
Broadcast/signaling	16.7	16.3	11.9
Service/traffic	20.8	20.4	14.5
Approximated extrapolation factor [dB]	4.1	4.1	2.6

Table 3. Maximum antenna gains and approximated extrapolation factor according to closed-form calculations

Beam type	Nominal max gain [dBi]	Calculated effective max gain [dBi]	
		LOS	*NLOS*
Broadcast/signaling	16.7	16.4	13.8
Service/traffic	20.8	19.5	15.9
Approximated extrapolation factor [dB]	4.1	3.1	2.1

4 Simplified calculation of effective maximum antenna gain

As presented by (2) the effective antenna pattern is assumed to be convolution of two gaussian signals, i.e. nominal antenna pattern with variance indicate by (B_{h0}^2, B_{v0}^2) and PAS with variance indicated by (σ_h^2, σ_v^2), where σ_h is RMS azimuthal angular spread and σ_v is RMS elevation angular spread, respectively, in given propagation environment. The resulting effective antenna pattern is also gaussian signal with variance indicated by $(B_{h0}^2 + \sigma_h^2, B_{v0}^2 + \sigma_v^2)$. Therefore, following (1) the maximum effective antenna gain can be determined by (5).

$$g_{\max}^{Eff} = \frac{2}{\sqrt{B_{h0}^2 + \sigma_h^2} \cdot \sqrt{B_{v0}^2 + \sigma_v^2}} \tag{5}$$

The RMS angular spread can be obtained from statistical channel models, like [8], measurements or ray tracing simulations and introduced into (5) to calculate the effective maximum antenna gain, as running of statistical simulations with (2) may not always be feasible. Afterwards, the calculation results can be used to improve accuracy of extrapolation factor introduced in [1].
Table 3 include results of calculations performed according to (5) for antenna beam patterns metrics from Table 1. As [8] does not include detailed information about antenna array layout, the parameters assumed in presented work have been selected to match metrics from Table 1, and used for calculations according to (5), which in more details is described in [3] and [10].

5 Conclusion

This paper discusses effective antenna pattern, especially maximum effective antenna gain, from the perspective of RF exposure evaluation for 5G with mMIMO and beamforming. It has been presented that the maximum effective antenna gain in realistic propagation environment is lower than maximum nominal antenna gain measured in anechoic chamber or ideal free space conditions. Difference between nominal and effective gains depends on the scattering intensity in the radio channel between transmitting antenna and the point of investigation and is noticeable especially in case of NLOS conditions The analysis has been performed using a representative commercially available antenna for which the ratio of service/traffic beam gain and broadcast beam gain has been calculated. Such approximation of extrapolation factor, as determined in [1], indicates that its value for analyzed antenna, working in 3.5 GHz frequency and deployed in UMa environment, can be overestimated by 1.5 dB to 2.0 dB for NLOS conditions if nominal antenna patterns are assumed instead of effective antenna pattern. Therefore, it is important to consider using the effective antenna gains in extrapolation factor to reduce overestimation of RF exposure.

7 References

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