FUTURE NETWORKS: 5G AND BEYOND

Proposal for simplified RF exposure assessment formula updates for millimetre wave small cells using beamforming

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Abstract/Résumé

Together with introduction of 5th generation (5G) of mobile communication system the millimetre wave (mmWave) frequency range is started to be utilized for personal mobile communication. Small cells deployment is typically assumed for mmWave as well as beamforming and beam steering of antenna radiation pattern. All this together enforce updates in current approaches for evaluation of radio frequency (RF) exposure, which were established and optimized for legacy systems. This paper proposes updates of simplified evaluation methods determined by International Electrotechnical Commission (IEC) for radio equipment working in frequency range between 2 GHz and 100 GHz covering mmWave. Proposed updates allow to improve the accuracy of simplified evaluation of compliance distances from mmWave small cell antennas which are capable to perform beamforming and beam steering.

1 Introduction

5th generation of mobile communication system (5G) starts utilization of millimetre wave (mmWave) frequency range for personal mobile communication. On top of that 5G introduces common use of beamforming with narrow-beam directional antennas and continues deployment of small cells for improvement of network capacity. Due to challenging propagation conditions in mmWave the most common deployment for this frequency range is small cell with high-gain directional antennas and beamforming, which creates a new study case from the perspective of radio frequency (RF) exposure assessment. International Electrotechnical Commission (IEC) in [1] and [2] defines simplified evaluation process of RF exposure from base stations (BS) of different classes, including low power small cells, which is based on International Commission on Non-Ionizing Radiation Protection (ICNIRP) [3] general public limits. This paper proposes update of approach presented in [1] and [2], which allows to minimize the simplified evaluation error in case of mmWave small cells with high-gain directional antennas and beamforming. Therefore, Section 2 discusses current versions of formulas for simplified evaluation of compliance distances according to [1] and [2]. Section 3 presents results of this simplified evaluation in reference to simulation results obtained from comprehensive computation model, whereas section 4 proposes how to improve the accuracy of simplified approach by minimization of evaluation error. Section 5 summarizes and concludes the paper.

2 Current small cell installation guidance with simplified verification process

IEC in section 6.2.4 of [1] defines simplified product installation evaluation process which applies to wide range of BS classes. Each class represents BSs with given range of applicable equivalent isotropic radiated power (EIRP), based on which the product installation criteria are defined. Currently, the simplified guidance of [1] are used with general public ICNIRP-based [3] exposure limits, however IEC is working on extended guidance that is applicable to other exposure limits than ICNIRP.

For frequency range between 2 GHz and 100 GHz, which includes mmWave range, the IEC recommends the minimum height (H_m) of the lowest radiating part of the beamforming antenna(s) above the general public walkway and the minimum distance (D_m) to areas accessible to the general public in the main lobe direction, as specified below by (1) and (2), respectively.

$$H_m = \max\begin{cases} 2 + \sqrt{\dfrac{EIRP \cdot A_{sl}}{10\pi}} \\ 2 + \sqrt{\dfrac{EIRP}{10\pi}}\sin(\alpha + 1.129\theta_{bw}) \end{cases} \tag{1}$$

$$D_m = \sqrt{\frac{EIRP}{10\pi}} \tag{2}$$

where:

A_{sl} is the side lobe suppression value in linear domain,

α is the total downtilt in [rad],

θ_{bw} is the vertical half power beamwidth (HPBW) in [rad].

As can be noticed, the outcome compliance distances from (1), i.e. H_m, depends on the way how the radiating directional antenna is forming the radiation pattern towards the point of investigation below the antenna. If the evaluated exposure is caused by the side lobes of static beam then the upper part of (1) applies. However, if the antenna is performing beam steering and is capable to tilt the beam towards the general public walkway, the lower part of (1) applies.

Because beamforming with beam steering are key features of 5G, the lower part of (1) will be investigated in further part of this paper, where updates of (1) and (2) are proposed to improve the accuracy of simplified evaluation of compliance distances for 5G mmWave small cells with beamforming and beam steering.

3 Simulations of RF exposure assessment for 5G mmWave small cell

To assess accuracy of simplified appoach presented by (1) and (2) the realistic RF exposure was calculated using the synthetic model method defined by IEC in section B.4.4.1 of [1] and [4] and disclosed by (3) below. This model allows to determine the electric field strength at a point of investigation as a vector sum of *n* small patches of the antenna treated as separate sources.

$$E = \sum_n \alpha_n \frac{\sqrt{30 \times P_n \times G_n}}{r_n} e^{j\left(\gamma_n + \frac{2\pi r_n}{\lambda}\right)} \tag{3}$$

where:

E is the electric field strength in [V/m],

r_n is the distance between the observation point and reference point of patch *n* in [m],

P_n is the input power to patch *n* in [W],

γ_n is the relative phase of applied voltage at antenna patch *n* in [rad],

G_n is the gain of patch *n* towards the point of investigation relative to an isotropic antenna in linear domain,

α_n is the weighting coefficient,

λ is the wavelength in [m].

Calculations were performed with the “EMF Visual” software release 4.0 [5] based on methods developed in [4]. RF exposure has been simulated for typical 5G mmWave (28 GHz and 39 GHz) small cell BSs with realistic RF parameters to increase the practicality of outcome results. Table 1 contains main RF parameters of BSs used for simulations, whereas Table 2 and Table 3 present compliance distances obtained from simulations for 28 GHz and 39 GHz cases, respectively. Table 2 and Table 3 include also simplified evaluations of D_m and H_m for parameters from Table 1 obtained according to (1) and (2) derived from [1].

As can be noticed, calculation results according to simplified approach (1) and (2) demonstrate overestimation of compliance distance in reference to simulation results based on synthetic model (3). In case of H_m the estimation error increase from around 20% to 120% in assumed range of EIRP. For both frequency cases, i.e. 28 GHz and 39 GHz, H_m estimation error is similar, however it increases together with the increase of downtilt, which has been illustrated in Figure 1.

In case of D_m the estimation error is above 100% in full range of assumed EIRP, whereas, for 39 GHz frequency and lower values of EIRP, it can be as high as 150-200%. More detailed illustration of D_m estimation error is presented in Figure 1.

It should be noted, that more comprehensive study with larger number of calculation results and wider range of frequencies would be needed to finally assess the accuracy of simplified approach, however results presented in this paper give already an overview on the range of possible estimation errors.

Table 1 : Main RF parameters of BS used for simulations of RF exposure

Parameter	**Value**			
Antenna array configuration	8(V) x 8(H) x 2(Pol)			
Frequency [GHz]	28		39	
Vertical HPBW (θ_{bw}) [°]	12.5		10.0	
Max total downtilt (α) [°]	30	45	30	45
EIRP [dBm]	44, 54, 64, 70	50, 54, 60, 64, 70	44, 54, 64, 70	50, 54, 60, 64, 70

Table 2: Simulation results and simplified calculations of compliance distances for 28 GHz case

Compliance Distance (28 GHz)									
EIRP [dBm] Downtilt [°]	44 30	50 45	54 30	54 45	60 45	64 30	64 45	70 45	70 30
Synthetic method results using (3)									
D_m [m]	**0.4**	**0.9**	**1.4**	**1.4**	**2.8**	**4.5**	**4.5**	**9.0**	**9.0**
$H_{u,d}$ [m]	0.1	0.5	0.7	0.8	1.7	2.2	2.7	5.7	4.6
H_m [m]	**2.1**	**2.5**	**2.7**	**2.8**	**3.7**	**4.2**	**4.7**	**7.7**	**6.6**
Simplified calculations using (1) and (2)									
D_m [m]	0.9	1.8	2.9	2.9	5.7	9.0	9.0	17.9	17.9
D_{m_adj} [m]	**0.5**	**0.9**	**1.4**	**1.4**	**2.9**	**4.5**	**4.5**	**9.0**	**9.0**
H_m [m]	2.7	3.6	4.0	4.5	6.9	8.3	9.7	17.3	14.5
H_{m_adj} [m]	**2.3**	**2.6**	**2.8**	**3.0**	**3.9**	**4.5**	**5.0**	**8.0**	**6.9**

Table 3: Simulation results and simplified calculations of compliance distances for 39 GHz case

Compliance Distance (39 GHz)									
EIRP [dBm] Downtilt [°]	44 30	50 45	54 30	54 45	60 45	64 30	64 45	70 45	70 30
Synthetic method results using (3)									
D_m [m]	**0.3**	**0.6**	**1.2**	**1.2**	**2.8**	**4.4**	**4.4**	**9.0**	**9.0**
$H_{u,d}$ [m]	0.2	0.5	0.6	0.8	1.7	2.1	2.7	5.3	4.3
H_m [m]	**2.2**	**2.5**	**2.6**	**2.8**	**3.7**	**4.1**	**4.7**	**7.3**	**6.3**
Simplified calculations using (1) and (2)									
D_m [m]	0.9	1.8	2.9	2.9	5.7	9.0	9.0	17.9	17.9
D_{m_adj} [m]	**0.5**	**0.9**	**1.4**	**1.4**	**2.9**	**4.5**	**4.5**	**9.0**	**9.0**
H_m [m]	2.6	3.5	3.9	4.4	6.7	7.9	9.5	16.9	13.8
H_{m_adj} [m]	**2.3**	**2.6**	**2.8**	**3.0**	**3.9**	**4.3**	**4.9**	**7.9**	**6.6**

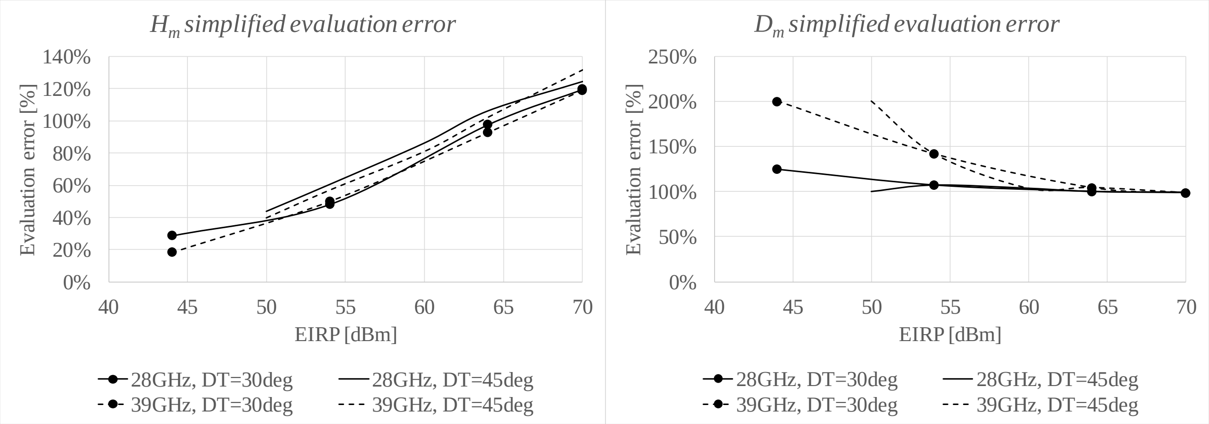

Figure 1 : Plots of simplified evaluation error in function of EIRP and downtilt

4 Modified small cell installation guidance with simplified verification process

As can be noticed, Table 2 and Table 3 contain also adjusted values of D_m and H_m, marked as D_{m_adj} and H_{m_adj}. Adjustment means that (1) and (2) have been modified to provide compliance distance aligned with results of exposure assessment simulations based on synthetic model method (3). Updated forms of (1) and (2) are presented below as (4) and (5), respectively. Increased have been constant factors for EIRP calibration, which has been changed from 10 to 65 and from 10 to 40 for H_m and D_m, respectively.

$$H_m = 2 + \sqrt{\frac{EIRP}{65\pi}}\sin(\alpha + 1.129\theta_{bw}) \tag{4}$$

$$D_m = \sqrt{\frac{EIRP}{40\pi}} \tag{5}$$

Updated formulas for simplified approach demonstrate reduced error in compliance distance evaluations. In case of H_m the estimation error is below 10% for all investigated cases, whereas D_m estimation error has been reduced by at least four times in comparison to results obtained by (2). Illustration of estimation errors for updated formulas is presented in Figure 2.

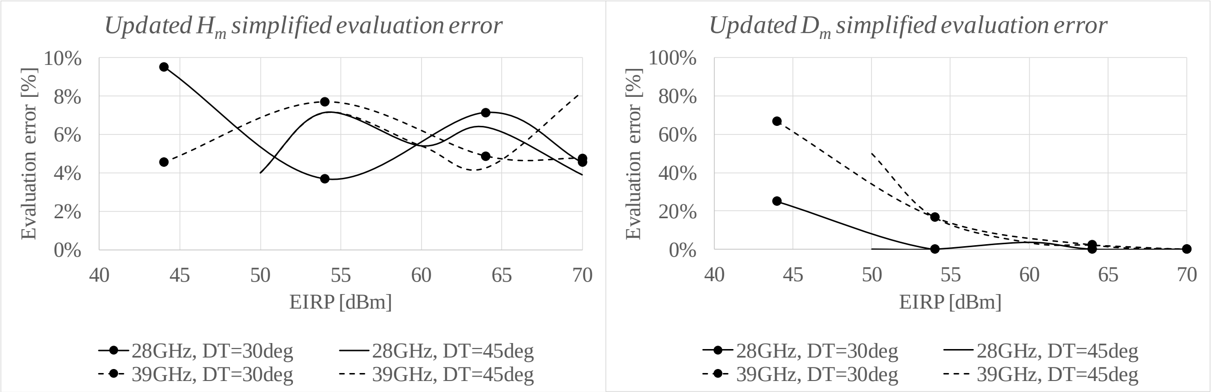

Figure 2 : Plots of updated simplified evaluation error in function of EIRP and downtilt

5 Conclusion

Modifications of simplified formulas introduced in [1] for product installation guidance have been proposed, which after additional verification can be part of future extensions of this guidance towards 5G mmWave small cell equipment with beamforming. Verified update is proposed for inclusion in future EMF exposure standards updates e.g. [1] and [6]. It is particularly important in the light of recent decisions made by World Radiocommunication Conference of 2019 (WRC-19) [7] on allocation of new mmWave frequency bands, e.g. 26 GHz, 39 GHz or 48 GHz, for 5G deployment. Updated formulas demonstrate reduced estimation error of compliance distances in comparison to current version of [1], but remain conservative compared to results obtained by synthetic model method.

References

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