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Monte-Carlo Simulation to Estimate Interference from 5G IMT System to Satellite Services in C-band

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Abstract

The deployment of 5G International Mobile Telecommunication (IMT) systems has raised concerns about their impact on existing satellite services. This paper develops a methodology to assess the keep-out distance of the satellite earth station from the 5G IMT base station. The study analyses interference power density for both Suburban and Urban areas in C-band using Monte Carlo simulations. The results provide protection distances necessary to meet the I/N protection criterion in both regions, considering the probability of I/N ratio through CDF plots. The findings emphasize the necessity of maintaining suitable separation distances between 5G IMT base station and satellite earth station in order to ensure acceptable interference levels.

1. Introduction

The need for fifth generation (5G) radio frequency communications is increasing at a high rate. The purpose of this study is to estimate interference between IMT services and satellite services in order to understand and evaluate the potential impact of 5G IMT systems, on satellite services operating in C-band using Monte Carlo (MC) simulations. By estimating interferences, it becomes possible to assess the coexistence between IMT and satellite earth station. As its significance has a prominent area of concern, the studies are going on to understand its complexities and its impact [1][2]. These studies do not account for dynamic generation of beam towards user equipment (UE), terrain details and receive Earth station operating scenarios like elevation angle. The method proposed in this paper addresses these parameters for estimation of interference levels.

Having 5G systems close to satellite ground stations raises concerns about interference that causes signal degradation and compromise communications links. The paper discusses the practical application of Monte-Carlo simulations for estimating interference levels, focusing on evaluating the interference power received from IMT base station to satellite earth station (ES) in both suburban and urban areas. By conducting extensive Monte Carlo simulations and creating multiple random scenarios, the study provides insights to assess the required protection distances to satisfy the interference-to-noise (I/N) protection criterion for satellite earth station operating in C-band.

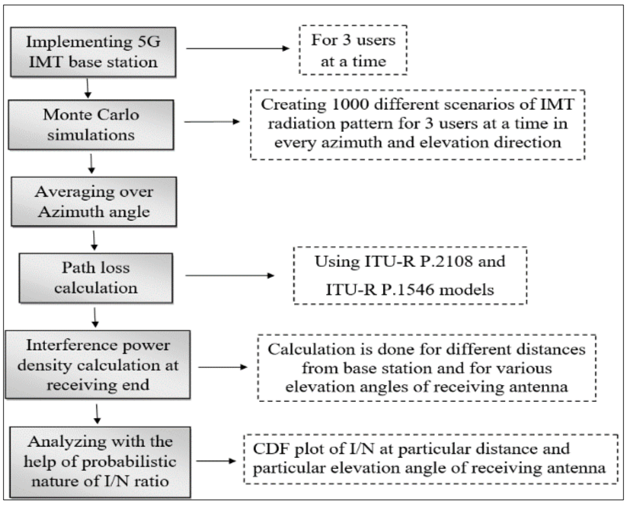

Figure 1. Monte-Carlo simulations to estimate interference to ES

2. Monte-Carlo Simulation

A. Analysis methodology

This paper is based on recent ITU recommendations and technical characteristics available for 5G IMT system and satellite earth station operating in C-band. The MC analysis simulation is depicted in figure 1. At first, 3# IMT users are randomly placed in the BS sector. Subsequently, 3# transmit beams are formed by BS towards users simultaneously using beamforming technology and transmit EIRP is measured in different azimuth and elevation directions. These two simulation steps are repeated for ~1000 times in-order to generate the average transmit EIRP in different azimuth and elevation directions within the BS sector. In the MC simulations, the transmit EIRP is averaged over azimuth angle range of ±180° to estimate the EIRP in different elevation range of 0° to 90°. We considered urban and suburban IMT BSs to generate the average transmit EIRP for estimation of interference to satellite receive ES. The averaged transmit EIRP is used to estimate the interference towards satellite receive ES. In the proposed method, we also considered clutter loss along with free-space path loss. Further, we considered satellite receive ES antenna elevation angle to simulate the receive antenna gain towards IMT BS. Single entry based interference analysis is proposed in this work to estimate the keep-out distance for co-existence between IMT BS and satellite receive ES. Major RF performance parameters of the IMT BS are given in Table 1. Earth station receive antenna radiation pattern follows ITU-R S.465-5 recommendation.

Table 1. Major RF performance parameters of 5G IMT system in C-Band

Horizontal 3dB bandwidth of element	90°
Front-to-back ratio: A_m and SLA_v	$A_m = 30$, $SLA_v = 30$
Vertical 3dB bandwidth of single element	65°
Element gain, $G_{E,max}$	6.4 dBi
Horizontal radiating element spacing $d/\lambda = d_h$	0.5
Vertical radiating element spacing $d/\lambda = d_v$	0.7
Down-tilt angle	6°
Frequency	3.4 GHz
Antenna Height	50m
Antenna array configuration (Rows x Column)	12 x 8
Bandwidth	100 MHz
Cell radius	800 m (Suburban) 400m (Urban)
Maximum BS output Power/sector (E.I.R.P)	72.3 dBm

B. Implementation of 5G IMT base station

The beamforming antenna is based on an antenna array and consists of number of identical radiating elements with a fixed separation distance. The total transmitting antenna gain is calculated as sum of the antenna gain of an element and the beamforming gain, which is determined by the azimuth and elevation angles in the antenna's main beam direction. The antenna gain of single element is given by,

$$A_E(\varphi,\theta) = G_{E,max} - \min\{-[A_{E,H}(\varphi) + A_{E,v}(\theta)], A_m\} \dots\dots\dots (i)$$

$G_{E,max}$ is the maximum antenna element gain. $A_{E,H}(\varphi)$ and $A_{E,v}(\theta)$ are the antenna radiation patterns in the horizontal and vertical directions, respectively. A_m is the front to back ratio of horizontal and vertical parameters. The IMT antenna array is $N_H \times N_V$ & composite antenna pattern for i^{th} user is calculated as,

$$G_{5G,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_v} w_{i,n,m} \cdot v_{n,m}\right|^2\right) \dots (ii)$$

where $A_E(\theta,\varphi)$ is antenna element gain and the super position vector $v_{n,m}$, and the weighting $w_{i,n,m}$ are given as per ITU-R M.2101-0 [3].

The composite pattern for the base station antenna should be used where the array serves one or more UEs with one or more beams. At first, we generated the pattern within the specified sector for three users at a time. To account for the variability and diversity of real world, we used Monte Carlo simulations to generate 1000 different scenarios of IMT radiation pattern, each representing unique UE position, as shown in figure 2.

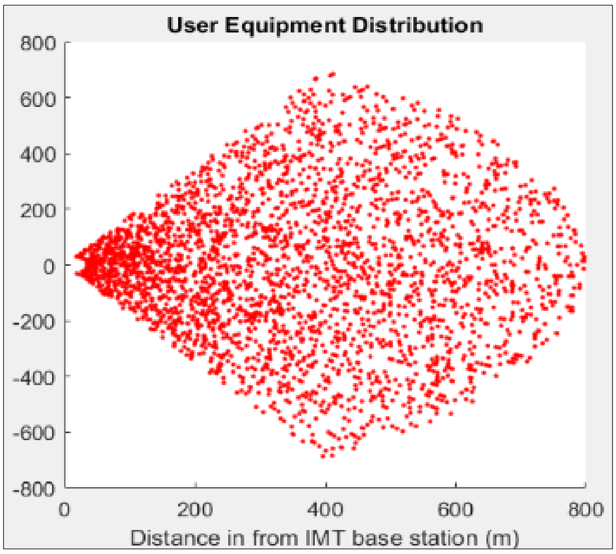

Figure 2. Distribution of UEs using Monte-Carlo simulation

The composite antenna pattern in the simulation has now been averaged over azimuth and plotted across elevation angles. This helps to evaluate average interference levels and understand overall antenna performance. Analysing the averaged antenna pattern is required for understanding RF performance of IMT base station. By forming radiation patterns in a sector, using Monte Carlo simulation, and analysing the average antenna pattern, we can assess IMT base station performance and can provide probabilistic interference power levels towards satellite receive earth station.

C. Path Loss

The simulation considers various propagation mechanisms between IMT BS and satellite receive earth station, including clutter loss, free-space propagation, and attenuation by atmospheric gases. However, our path loss calculation for C-band includes the Free Space Path Loss (FSPL) and the clutter loss beyond 2 km distance using ITU-R P.1546 model [4], which provides more comprehensive estimation of path loss which is shown in figure 3. We assumed the clutter height of 10m in suburban scenario and 15m in urban scenario. We also assumed the satellite receive antenna hight of 10m. Received interference power density (I_0) of signal from a 5G IMT

BS at a satellite receive Earth station is estimated as using IMT BS transmit EIRP ($EIRP_{IMT\ BS}$) & bandwidth (BW), receive earth station antenna gain (G_{ES}) and path loss (PL) which is given in equation (iii).

$$I_0\left(\frac{dBW}{Hz}\right) = EIRP_{IMT\ BS}(dBW) + G_{ES} - PL(dB)$$
$$-BW(dBHz) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

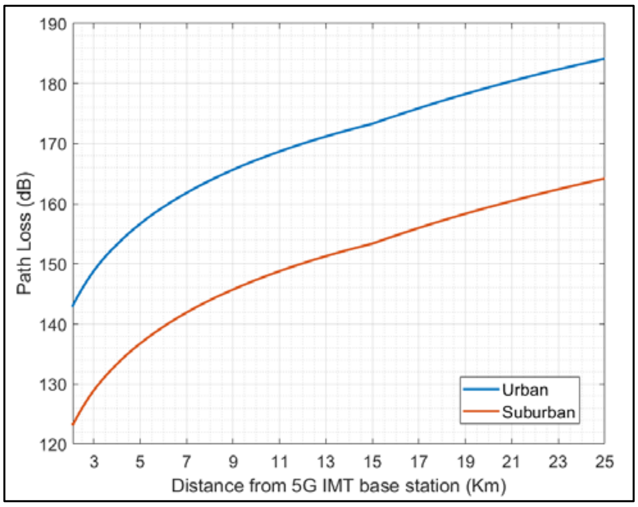

Figure 3. Path loss beyond 2km distance

3. Interference Analysis

The cumulative density function (CDF) plot of the estimated interference power density for each iteration is created and compared to the protection criteria until required protection distance is achieved. Based on the criteria given in ITU-R S.1432 [5], in our simulation, we use I/N = −12.2 dB as the interference threshold. The CDF plots of I/N for urban and suburban scenarios are shown in figure 4 and figure 5 respectively. We can conclude that the protection distance between 5G IMT base station and satellite earth station for 40º elevation of receiving antenna is ~30 km in Suburban and ~7 km in Urban.

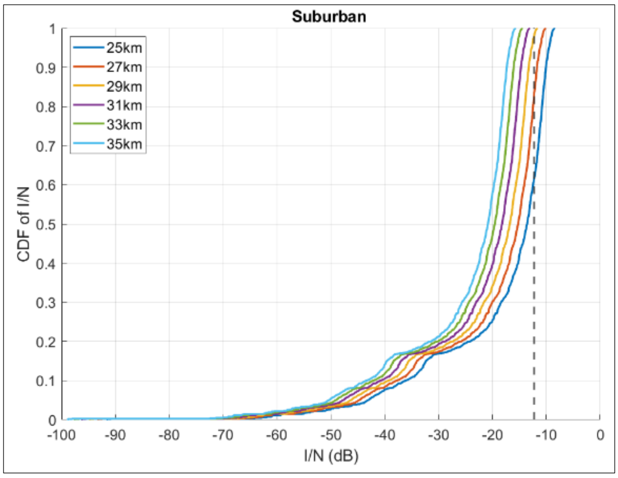

Figure 4. CDF Plot of I/N at 40º elevation of receive antenna for suburban

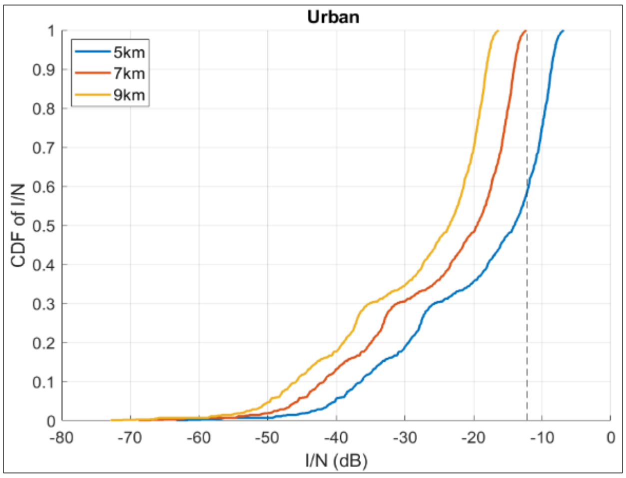

Figure 5. CDF Plot of I/N at 40º elevation of receive antenna for urban

4. Conclusion

This paper proposes the Monte-Carlo simulation methodology to estimate the interference level from 5G IMT BS towards satellite receive Earth station. Using the proposed method, we estimate the minimum protection distance required between 5G IMT BS and satellite receive Earth station with 40° elevation angle to meet the I/N protection criterion of -12.2 dB. The study presents the CDF of I/N for urban and suburban scenarios. The proposed can be used for estimation of the I/N for various scenarios like different terrain and various elevation angles.

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7. References

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