Simulation of the Received Signal Power in a Mobile Telephony Cell

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ABSTRACT

This report studies the free-space path loss model in different terrains and simulate the received power and Bit Error Rate (BER) at different locations in the grid. The received power and BER is determined in Line of sight (LOS) and non-Line of Sight (nLOS) and other channel conditions to analyze the network efficiently. Modulation schemes like Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16 – Quadrature Amplitude Modulation (QAM), 32 – QAM and 256 – QAM are simulated to determine the BER in the grid in different LOS and nLOS conditions.

I. INTRODUCTION

Wireless communication demand detailed study in various environment models to better understand the network parameters. Simulation is commonly used for wireless research due to the high cost of network analyzers and setup while conducting experiments in real time. It is difficult to reproduce the results, either across different testbed sites or at different times due to the change in conditions. In simulations, we can replicate our results and reproduce, debug and work on them at any place in the world. One such model is NS-3 [1] which can help in answering the network performance questions.

In this report, we studied the performance of simple free-space path loss model and simulated it in MATLAB 2021b under different user-defined network parameters. A channel model is created to generate the received power and BER at different locations in a grid. The grid consists of a transmitting antenna, receiving antennas and different sizes of obstacles. We also tried to determine the LOS and nLOS conditions based on the transmitter (Tx) and receiver (Rx) locations and the obstacles present between them. Since this is an initial study, we considered some assumptions to determine the presence of LOS or nLOS between the Tx and Rx. We also studied some working examples of the simulated model to better understand the network performance under various LOS and nLOS conditions.

In this report, we present the network model description in Section II and evaluate and propose a suitable model in Section III of the report. We analyze the model in Section IV and present some working examples of the network model under study. The report is concluded in Section V.

II. NETWORK MODEL

Assuming a square region, surrounding a cell tower, is divided into a grid. We need to generate the received power in each grid, and the Bit Error Rate (BER) at each location.

Transmitter model:

The user can define the following parameters for the transmitter side simulation,

- *Transmitted Power*
- *Noise Power Spectral Density (PSD) (1 nW to 1microW)*
- *Link bit rate*
- *Constellation used*
  - *BPSK*
  - *QPSK*
  - *QAM-16*
  - *QAM-32*
  - *QAM-256*

Channel model:

The user can define the following parameters for the channel model simulation,

- *Transmitter (Tx) antenna height*
- *Receiver (Rx) antenna height*
- *Tx antenna gain*
- *Rx Antenna gain*
- *Carrier frequency (f_c)*
- *Grid size (in meters)*
- *Grid resolution*
- *Terrain type*
  - *Flat*
  - *Random small hills (up to 2 meters)*
  - *Random large hills (up to 5 meters)*
  - *Mountain (up to 10 meters)*
- *Obstacle height*

III. PROPOSED MODEL

A. Model Parameters

Parameters discussed in the Section II of the report are using the values mentioned in the Table 1 below.

Parameters	*Values*
Transmitter antenna gain, Gt	*10 - 100*
Transmitter antenna height, Tx_ht	*4 m – 20 m*
Receiver antenna gain, Gr	*2*
Frequency, freq	*(700 – 800) MHz*
Transmission power, Ptx	*100 mW – 5 W*
Noise power spectral density, N_psd	*1 nW – 1 µW*
Path loss exponent, beta	*1 – 2 (Urban areas)* *3 – 5 (microcells)*
Grid length and width, g_lt	*10 m – 50 m*
Grid resolution, g_res_x_y	*3 - 31*
Constellation	*1 – BPSK* *2 – QPSK* *3 – 16 QAM* *4 – 32 QAM* *5 – 256 QAM*
Bit rate, bit_rate	*1 – 3 Kbps*

Table 1. Model parameters

B. Channel model

The first step in creating the channel model is to create a grid matrix in MATLAB from the user-defined inputs. Each point on the matrix indicates the terrain height to determine the Line-of-Sight (LOS) or Non-LOS (nLOS) for each grid from the transmitting antenna system.

Assumptions

- *I am assuming equal grid distribution in x- and y-direction.*
- *Establishing the Tx antenna system in the middle grid of each simulation.*

From the above assumptions, Figure 1 shows an example of the grid matrix of size 19 x 19. I am considering a moderate density of obstacles in my grid by assigning only 0 m, 2 m, and 5 m at each resolution of the grid. The obstacles height was assigned randomly in the simulation. The transmitter antenna is placed at the center of the grid to serve each part of the grid equally.

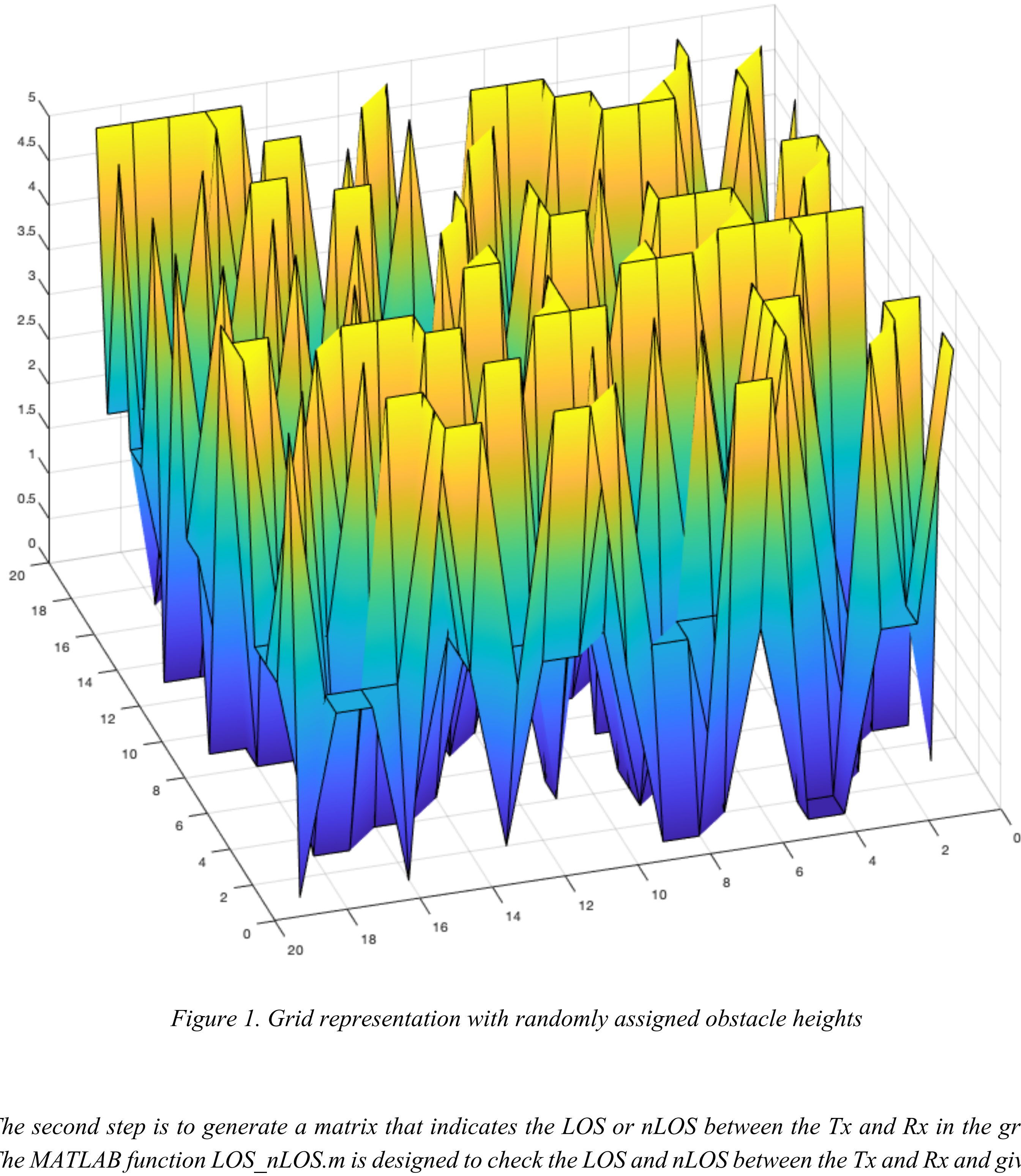

Figure 1. Grid representation with randomly assigned obstacle heights

The second step is to generate a matrix that indicates the LOS or nLOS between the Tx and Rx in the grid. The MATLAB function LOS_nLOS.m is designed to check the LOS and nLOS between the Tx and Rx and gives the output as value 1 if there is a LOS, and the value 2 if there is a nLOS. The matrix state_mat indicates the LOS or nLOS between each grid in the simulation model. Determining a LOS or nLOS between Tx and Rx depends on multiple parameters making it one of the crucial and toughest part of the simulation. For *simplicity, I am assuming a LOS for the grids which are near to the Tx antenna and a nLOS case for all the other grids present in the model. The state_mat given below shows the LOS and nLOS case in a 7 x 7 grid. The value 1 in the middle of the matrix indicates the LOS case around the Tx antenna, and the value 2 is the nLOS case in all the other grids.*

state_mat =

2	2	2	2	2	2	2
2	2	2	2	2	2	2
2	2	1	1	1	2	2
2	2	1	1	1	2	2
2	2	1	1	1	2	2
2	2	2	2	2	2	2
2	2	2	2	2	2	2

The third step is to generate a matrix to determine the accurate distance between the Tx and Rx. The Euclid_Dist matrix represents the Euclidean distance between the Tx and Rx to calculate the received power in the next step. The Euclid_Dist given below shows an example of the Euclidean distance between the Tx and Rx on a 7 x 7 grid model. The value 0 in the middle shows that the Tx is placed in the middle of the grid, and all the other values are the Euclidean distance of each grid from the Tx.

Euclid_Dist =

30.3046	25.7539	22.5877	21.4286	22.5877	25.7539	30.3046
25.7539	20.2031	15.9719	14.2857	15.9719	20.2031	25.7539
22.5877	15.9719	10.1015	7.1429	10.1015	15.9719	22.5877
21.4286	14.2857	7.1429	0	7.1429	14.2857	21.4286
22.5877	15.9719	10.1015	7.1429	10.1015	15.9719	22.5877
25.7539	20.2031	15.9719	14.2857	15.9719	20.2031	25.7539
30.3046	25.7539	22.5877	21.4286	22.5877	25.7539	30.3046

The fourth step is to calculate the received power in each smaller grid. The MATLAB function RxPower.m calculates the received power at each grid based on the LOS/nLOS matrix generated in the second step, and the Euclid_Dist matrix generated in second step. We will use these values to generate the heat map for the received power at each grid in later part of the simulation. Figure 2 shows the received power heat map for *a grid of 15 m with a resolution of 17. The received signal power will be high near the Tx antenna shown by the light side in the heatmap and drops as the Rx starts moving away from the Tx indicated by the dark sides in the heat map. First, the received power at distance d = 1 m is calculated using the free-space propagation equation,*

$$\alpha = P_t\, G_t\, G_r \left(\frac{\lambda}{4\pi}\right)^2 \tag{1}$$

where:

- *α is the received power (watts) at 1 meter.*
- *P_t is the transmitted power (watts).*
- *G_t and G_r are the gains of the transmitter and receiver antennas, respectively.*
- *λ is the carrier wavelength.*

The received power at distance d under LOS conditions is given by

$$P_{RX}(d) = \alpha \left(\frac{1}{d}\right)^{\beta} \tag{2}$$

Typical values of β are 1 to 2 in urban areas or in indoor hallways, and 3 to 5 in microcells.

Under nLOS conditions, the received power is reduced by a further 30 dBm.

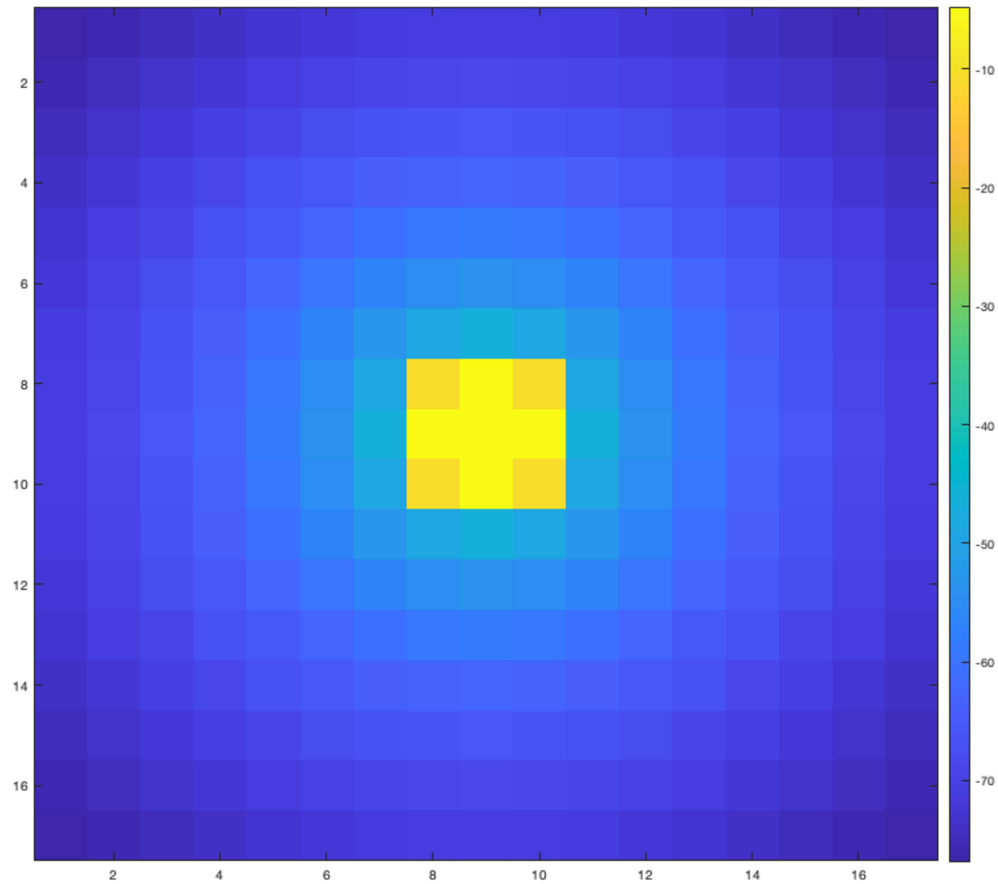

Figure 2. Received power (dBm) heatmap in a 15 m x 15 m grid with resolution of 17

We now calculate the BER in the grid using the function BER_map(). It takes the bit rate, received power, noise PSD, and modulation scheme as the input, and calculates the SNR and BER at each resolution in the grid. Theoretical BER values given in the equation (3), (4), (5), (6) and (7) for each modulation scheme are used to generate accurate BERs in the grid.

$$BPSK\ P_e = Q(\sqrt{2 \,.\, SNR}) \tag{3}$$

$$QPSK\ P_e = 2\ Q(\sqrt{2 \,.\, SNR}) \tag{4}$$

$$16\text{ - }QAM\ P_e = Q(\sqrt{\tfrac{4}{5} \,.\, SNR}) \tag{5}$$

$$32\text{ - }QAM\ P_e = \tfrac{4}{5}\ Q(\sqrt{\tfrac{15}{31} \,.\, SNR}) \tag{6}$$

$$256\text{ - }QAM\ P_e = \tfrac{1}{2}\ Q(\sqrt{\tfrac{8}{85} \,.\, SNR}) \tag{7}$$

Figure 3 shows the BER for BPSK constellation and the parameters mentioned in Table 1. We can see that the grids placed near the Tx antenna will be in the LOS resulting in low BER, whereas the farther areas will experience high BER due to the nLOS case and large Tx-Rx distances. High BER is shown by the light side in the heatmap and low BER by the dark sides in the heatmap. Fig

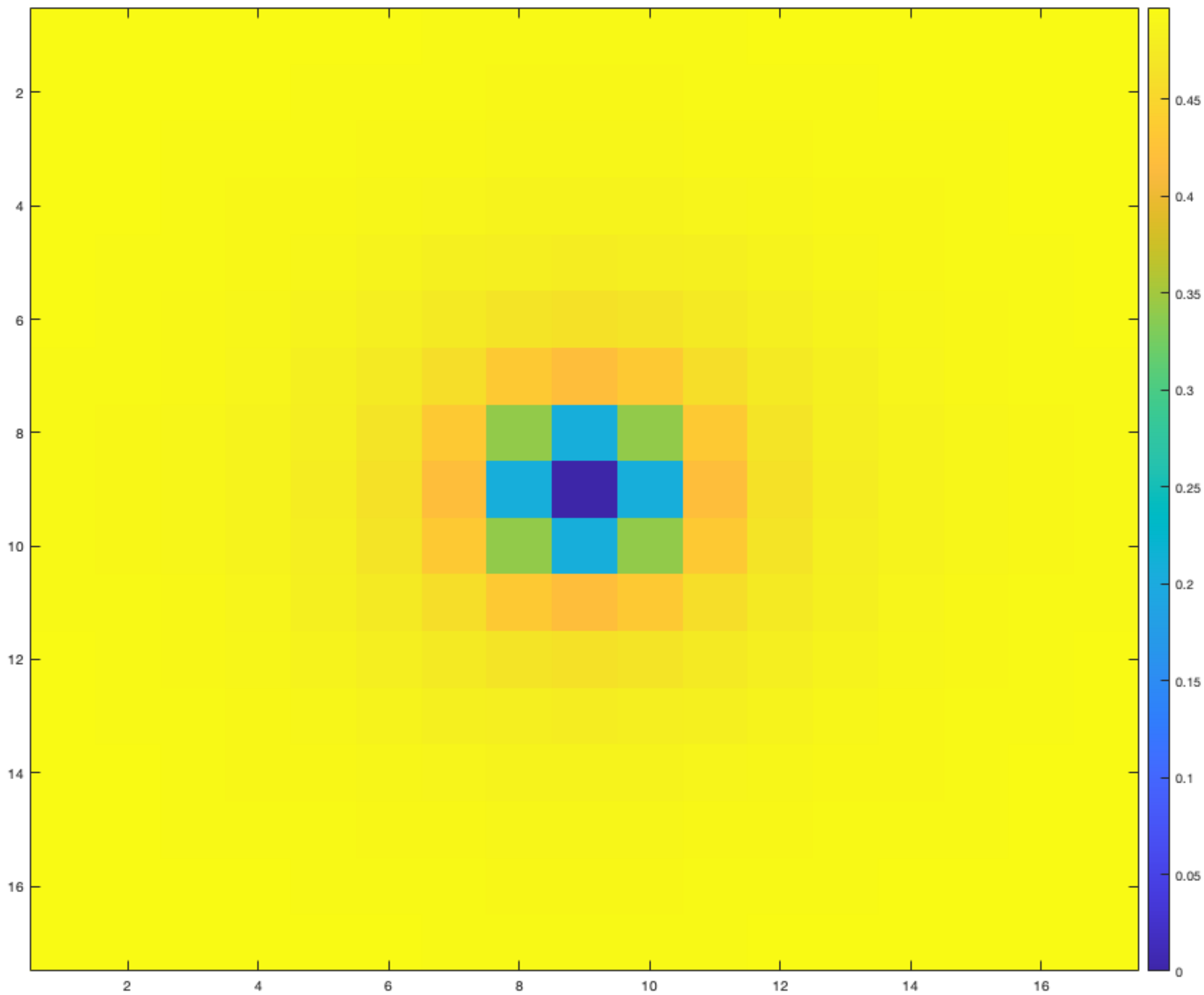

Figure 3. BER heatmap for BPSK in a 15 m x 15 m grid with resolution of 17

IV. RESULTS

First the model is studied in only LOS condition to observe the Rx power and BER heatmaps. Figure 4 and Figure 5 show the Rx power and BER heatmap in only LOS condition in a 30 m x 30 m grid with resolution *of 21. In a LOS condition, the received power will be higher than the nLOS case by 30 dBm. We can see that the Rx power ranges from -15 dBm to – 60 dBm in LOS condition, and the BER ranges from 0 - 0.45.*

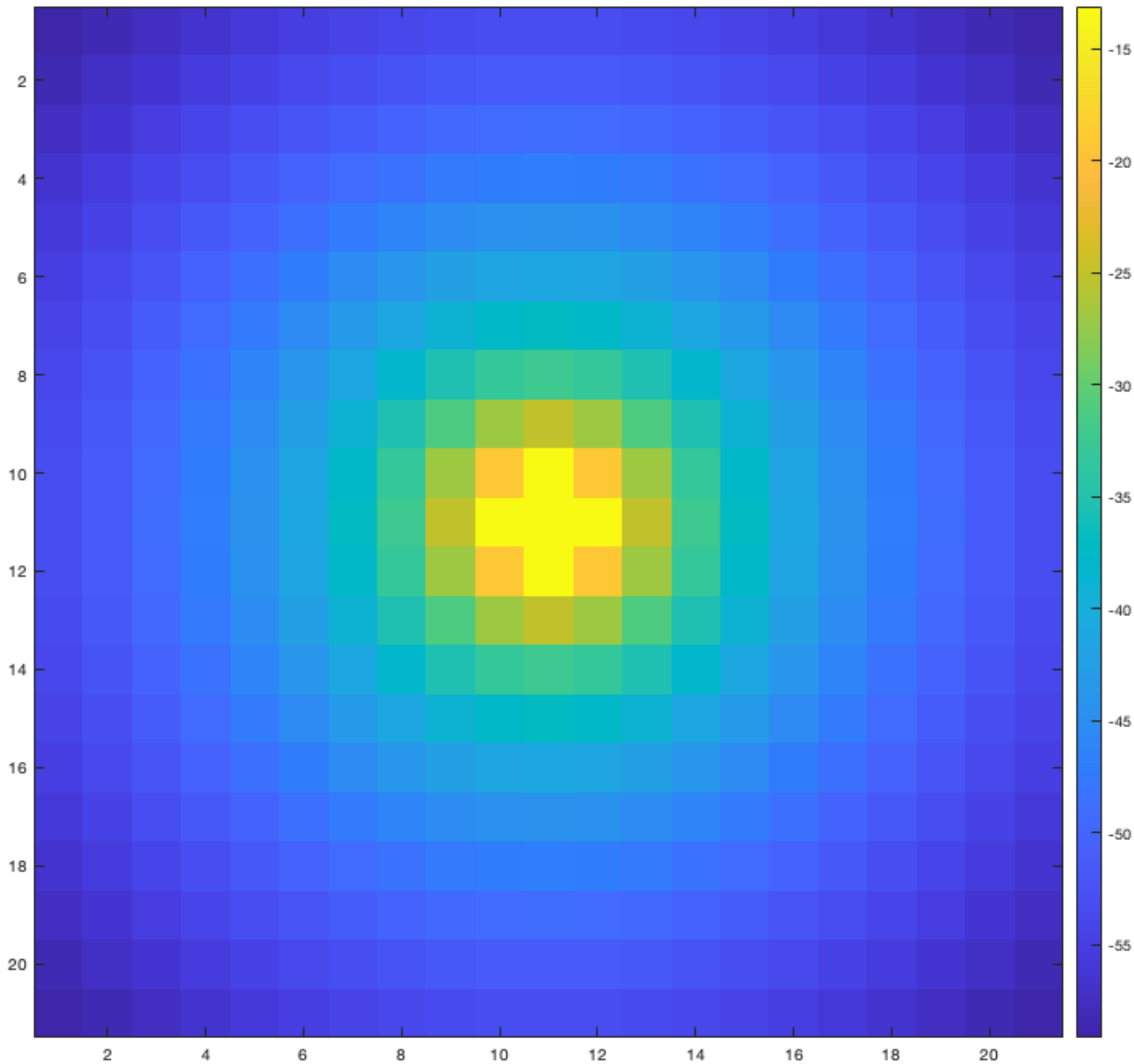

Figure 4. Rx power (dBm) heatmap in LOS condition in a 30 m x 30 m grid with resolution of 21

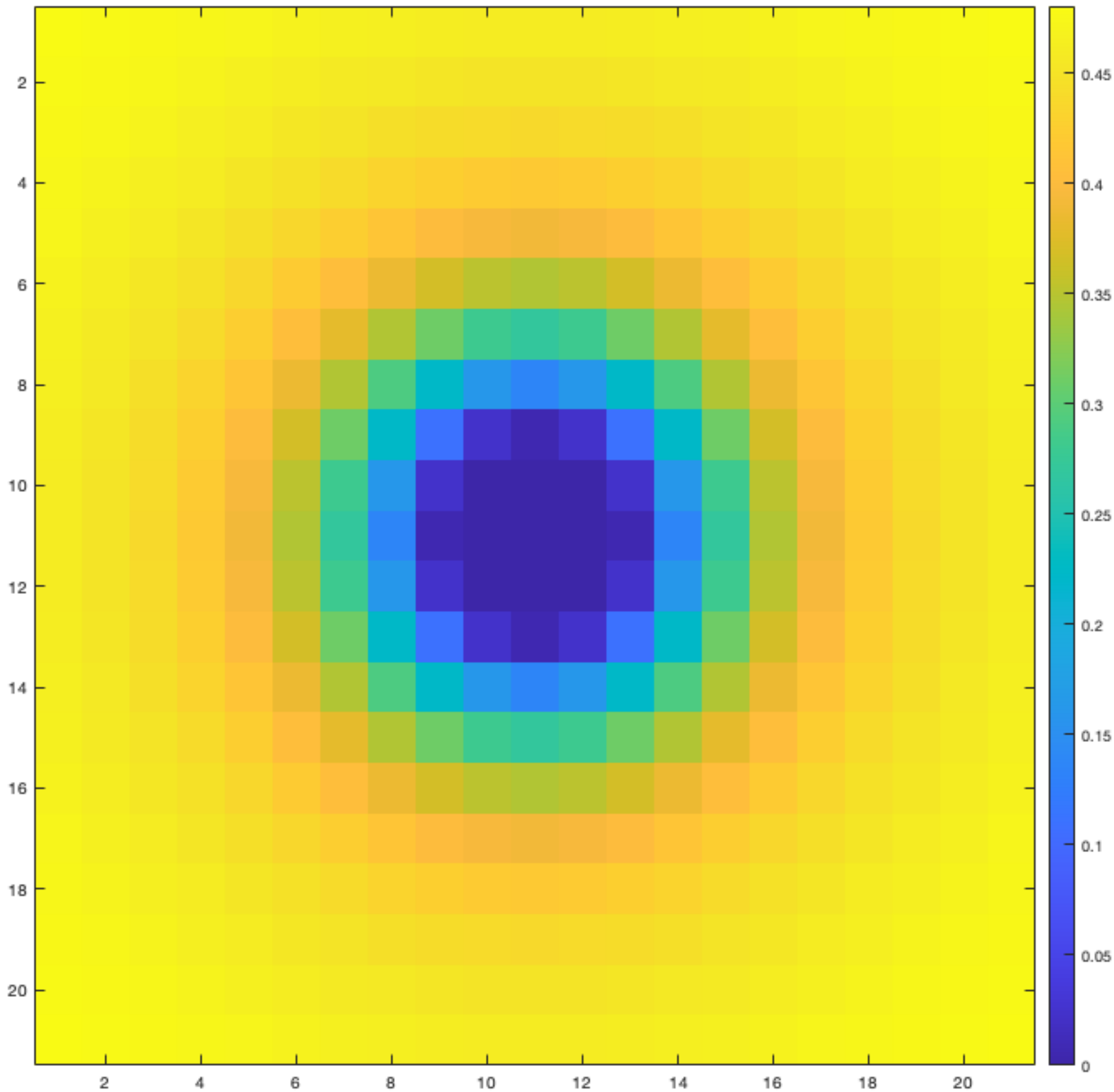

Figure 5. BER heatmap in LOS condition in a 30 m x 30 m grid with resolution of 21

In our next example, we will study the Rx power and BER heatmaps in only nLOS condition as shown in Figure 6 and Figure 7.

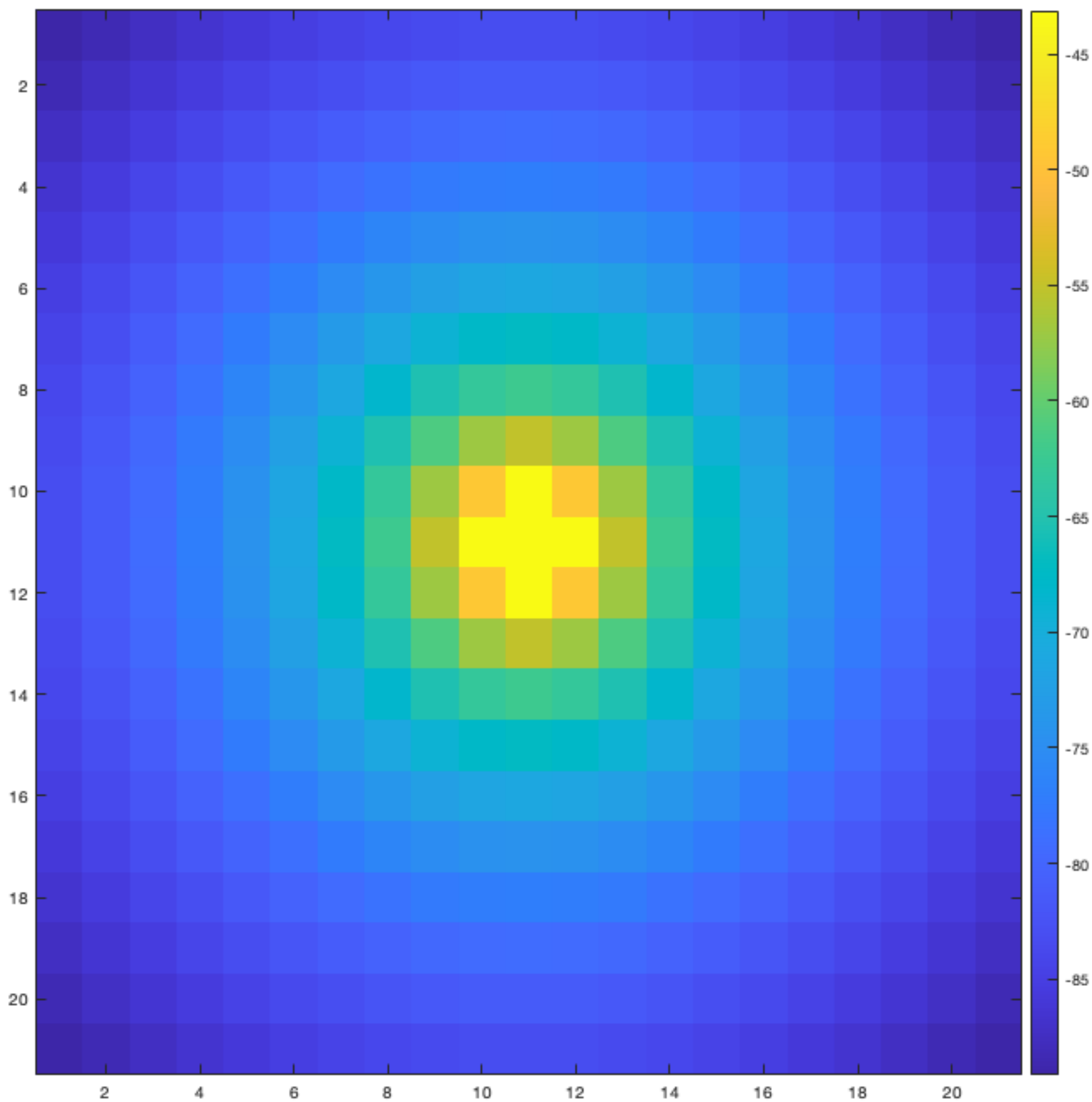

Figure 6. Rx power (dBm) heatmap in nLOS condition in a 30 m x 30 m grid with resolution of 21

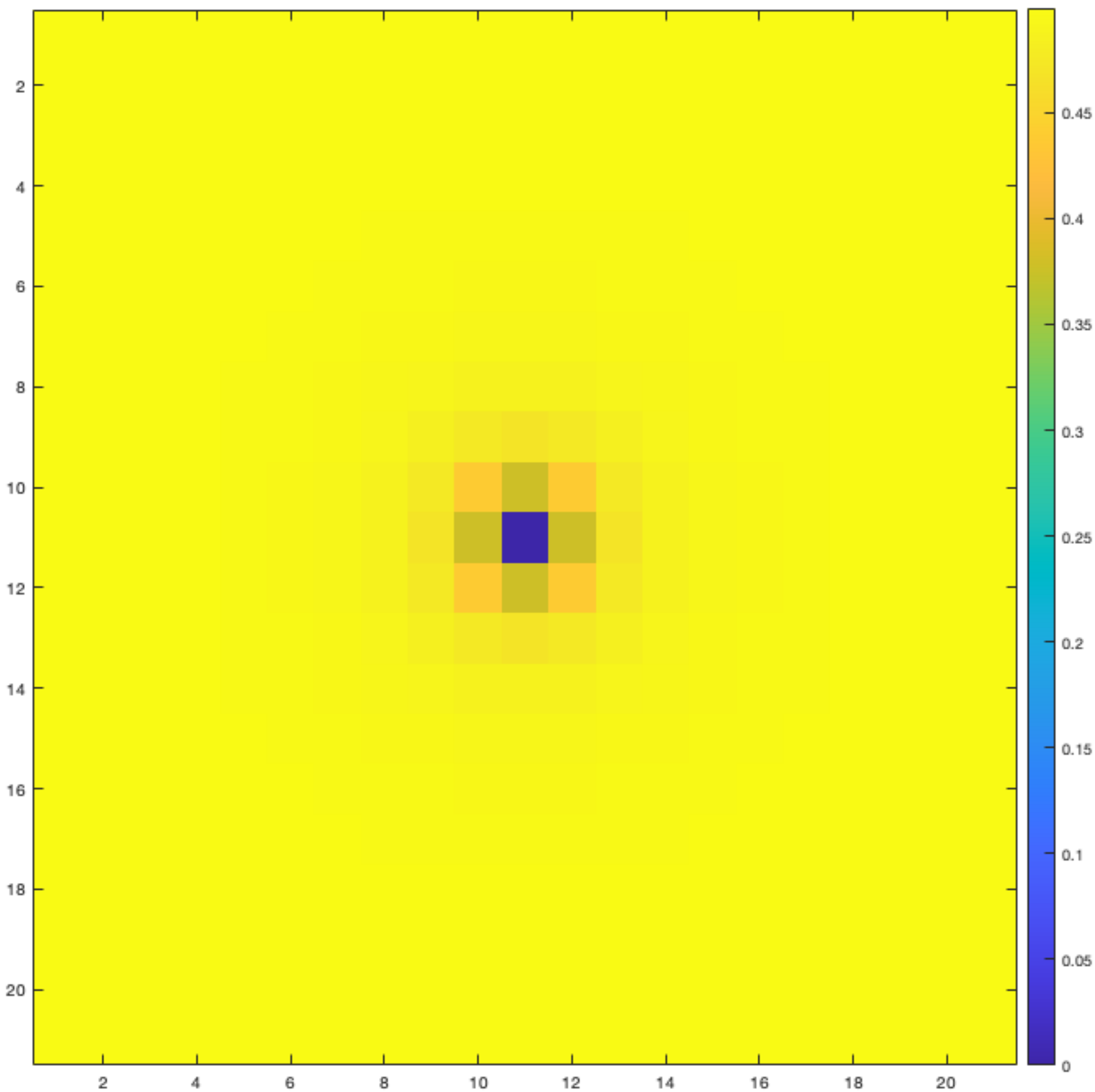

Figure 7. BER heatmap in nLOS condition in a 30 m x 30 m grid with resolution of 21

We observe that the Rx power reduced by 30 dBm in nLOS case as expected. This shows that the model calculates the Rx power accurately based on the LOS and nLOS channel conditions.

V. CONCLUSION

In this report, we studied various aspects of the simulation model under the LOS and nLOS channel condition. In particular, the received power and BER were studied and showed that the model works properly *in LOS and nLOS conditions and generates accurate received power based on the given free-space propagation model. The theoretical model of BER for various modulation schemes was also simulated and a heatmap was generated for LOS and nLOS conditions. In the future, we aim to determine the LOS and nLOS condition in a better way and simulate the transmitter and receiver model with different bit rates.*

References

[1] M. Mezzavilla et al., "End-to-End Simulation of 5G mmWave Networks," in IEEE Communications Surveys \& Tutorials, vol. 20, no. 3, pp. 2237-2263, third quarter 2018, doi: 10.1109/COMST.2018.2828880.