B.Tech Project Report

Study of RF Spectrum Coexistence Problem between 5G Cellular Systems and Fixed Satellite Services

submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology
in
Electronics and Telecommunication Engineering

under the guidance of

Dr. Tamaghna Acharya
Associate Professor, HoD
Electronics and Telecommunication Engineering
Indian Institute of Engineering Science and Technology, Shibpur

by

Avradeep Neogi (2021ETB040)
Himadri Chattopadhyay(2021ETB039)

DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATION ENGINEERING

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR

DECLARATION

We hereby declare that this thesis entitled "***Study of RF Spectrum Coexistence Problem between 5G Cellular Systems and Fixed Satellite Services***", contains a literature survey , original research and future work , done by the undersigned candidate, as part of our degree of Bachelor of Technology in Electronics and Telecommunication Engineering We also declare that we have fully cited and referenced all materials and results that are not original to this work.

We authorise the Indian Institute of Engineering Science and Technology, Shibpur, to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Avradeep Neogi
2021ETB040
Himadri Chattopadhyay
2021ETB039

Department of E&TCE
IIEST, Shibpur

ACKNOWLEDGEMENT

We would solely like to express our deepest gratitude to our advisor and supervisor, Dr.Tamaghna Acharya, Associate Professor, Department of Electronics and Telecommunication Engineering, Indian Institute of Engineering Science and Technology, Shibpur, for his guidance, patience and motivation. His valuable insight, experience and moral support helped me a lot in my project and completing my thesis work.

Last but not the least, my parents played a crucial role in endeavoring the success and mental stability.

This thesis would not have been possible without the inspiration and support of a number of wonderful individuals- we extend our thanks and appreciation to all of them for being a part of this journey and making this possible.

INTRODUCTION

The coexistence of 5G cellular systems and Fixed Satellite Services (FSS) presents significant challenges and opportunities in the radio frequency (RF) spectrum, especially as both services demand access to overlapping frequency bands. As 5G networks expand globally, they require high-bandwidth spectrum, often in the C-band (3.4-4.2 GHz) and mm wave-band (26.5-40 GHz), where FSS traditionally operates. This overlap creates potential interference issues, as signals from terrestrial 5G base stations could disrupt the reception of satellite signals, affecting services such as broadcasting, data relays, and emergency communications.

Managing this coexistence involves developing sophisticated techniques for interference mitigation, including dynamic spectrum access, Active Antenna System (AAS) as recommended by International Telecommunication Union (ITU), and filtering technologies. Regulatory frameworks are also being adapted to create shared or segmented spectrum allocations, ensuring both 5G and satellite systems can operate without harmful interference. Different Path Loss models are also implemented to theoretically simulate maximum interference power between Base Station (BS) and Earth Station (ES) antennas.

PREVIOUS YEAR WORK

Previously, our seniors had worked on discussing the system model for the normal mode forward link coexistence scenario between 5G and FSS, and introduced the corresponding transmitter, receiver models and channel model, mainly the path-loss models. It also includes analytical expressions for interference when beamforming is used at the BSs on Transmitter-Receiver model of 5G coexistence of Base Station (BS) and Fixed Satellite Service (FSS) antennas and modeling their radiation pattern , analytical expression for interference between them, calculating performance for both omnidirectional and directional antennas, modeling network characteristics, simulating aggregate interference for both omnidirectional and directional antennas. All these modeling and simulation are done in C band.

In the mm - wave band, they have done simulations of expected interference against different terrains by varying the protection radius. The model they have used for the reference is the Stanford University Interim (SUI) model[1].

Their contribution can be broadly classified into the following domains:

A. System Model :

These are the important assumptions of this project

(a) All BSs are transmitting at the same time.
(b) Terrestrial BSs are uniformly distributed in the annular region. There is no BS inside the inner radius R0, i.e. Protection Radius.
(c) About the BSs individual user equipment are distributed uniformly in their cell, and the BS engages its entire frequency spectrum for the User Equipment (UE).
(d) Continuous assignment of Bandwidth, each user is assigned 5MHz (in C-band scenario) and 200MHz (in mmWave scenario).
(e) In case of omnidirectional antenna, the BS transmits equally in every direction. In case of AAS, the direction of the main beam of the base station antenna is towards the users.
(f) The carrier frequency for the satellite forward link is chosen to be the central frequency of the spectrum used for the satellite communication.
(g) The recommended interference to noise ratio is I/N = −10dB.

B. Network Model :

Several Base Stations are deployed in an annular ring with the FSS at the center. Each cell is considered to have only one base station, and due to uniform distribution, the cells are approximately of similar sizes. As will be mentioned below, we are considering two types of scenarios for base station antennas, one where beamforming is used, one where beamforming is not used. If beamforming is considered, to get the interference contribution of each base station we need to add up interference caused at the FSS end by each individual user equipment in the cell, as gain of the transmitter in the direction of the FSS antenna will vary each time. We need not consider user equipment in each cells if there is no beamforming at the base station.

C. 5G Cellular Base Station Transmitter Model:

We have considered two scenarios- when the BSs are equipped with AAS and omnidirectional antenna respectively, to compare the performance. For modeling the AAS, the document 3GPP TR 37.840 [2] is refered, where a planar Uniform Rectangular Array (URA) antenna with (NV × NH) elements are placed along the vertical and horizontal axes respectively. The 3D radiation pattern is computed using the expression provided in Table 5.4.4.2-3 of [2]. It can be observed that a maximum gain is achieved at θ = 90◦ and ϕ = 0◦. For modeling the omnidirectional antenna, the gain is uniform in every direction irrespective of any angle.

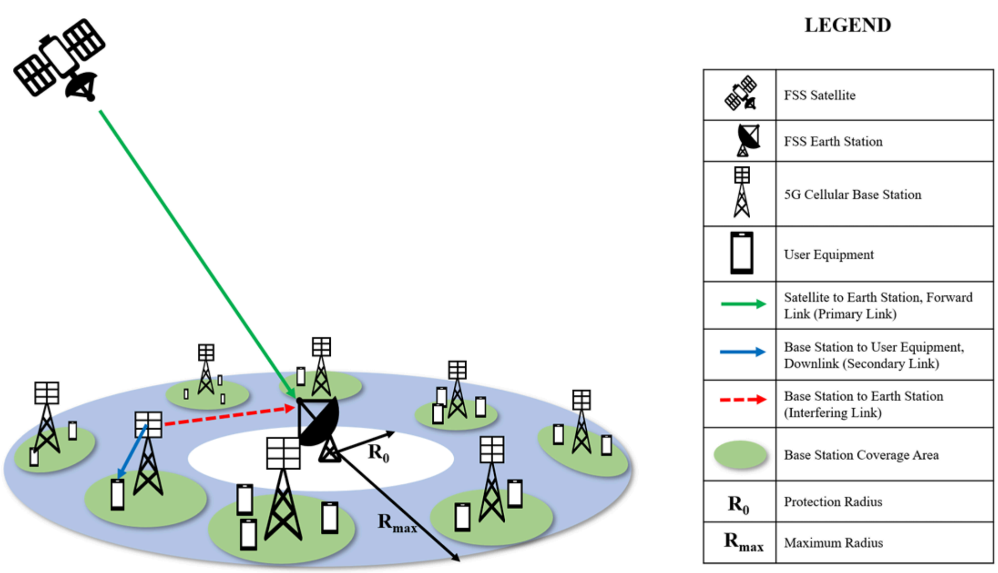


Fig. I

D. FSS Earth Station Receiver Model:

Along with the antenna, there is a square root raised cosine(SRRC) filter used as the receiver, whose response curve for the band of interest, i.e. 3.4-3.8GHz. The filter equation is given by

$$G_{filter} = \begin{cases} 304 * (f * 10^{-9} - 3.625)\ dB & \text{if } 3.4GHz \le f < 3.625GHz \\ 0\ dB & \text{if } f > 3.625GHz \end{cases}$$

…… Eq (1)

OUR CONTRIBUTION

Mainly we have replicated the previous year work in this semester. We have tried this approach to feel quite confident and track our understanding and progress. So, basically the work done in this semesters are listed below :

1. Replication of AAS antenna pattern, modeled according to [2].

2. Replication of FSS Earth Station Dish Antenna Pattern, simulated according to [3].

3. Replication of FSS Earth Station Receiver Filter Response, according to Eq (1).

4. Estimate deployment of cell towers using Monte Carlo simulation

5. Plotting interference vs mean density at centre of annular disc like distribution by power law path loss model, according to [8]

6. Plotting Pathloss vs Distance curve according to Recommendation ITU-R P.1546-6 [4].

7. Potting interference vs mean density at centre of annular disc like distribution by using Recommendation ITU-R P.1546-6 [4].

8. Getting Pathloss vs distance Curve and data for T-DUP model, according to [5].

9. Comparison of the various path loss model, according to [6].

1. Replication of AAS antenna pattern :

The antenna pattern of Active Antenna System (AAS) is modeled according to [2]. The average BS height is taken as hbs = 25m.[6]. A planar Uniform Rectangular Array (URA) antenna with (NV × NH) elements are placed along the vertical and horizontal axes respectively to simulate the results. The 3-D picture in Fig. II shows the radiation pattern of the AAS and the Table. I indicates the parameters used in this simulation.

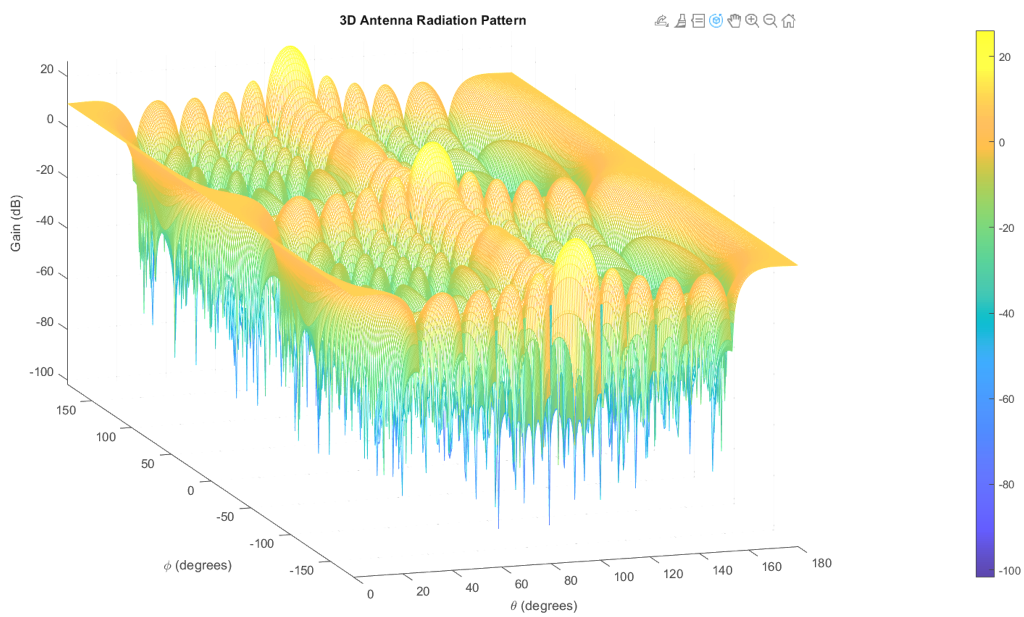


Fig. II

Table. I - Parameters used for AAS Pattern

Parameter	Value
Horizontal element spacing (d_H)	0.7λ
Vertical element spacing (d_V)	0.7λ
Downward tilting angle w.r.t boresight (θ_{etilt})	0°
Horizontal scan angle w.r.t boresight (ϕ_{escan})	0°
3 dB elevation beamwidth (θ_{3dB})	65°
3 dB azimuth beamwidth (ϕ_{3dB})	65°
No. of elements in a vertical row (N_V)	8
No. of elements in a horizontal row (N_H)	8
Side-lobe Ratio (SLA_V)	30 dB
Front-to-back Ratio	30 dB
Maximum element gain ($G_{E,max}$)	8 dB
Carrier Frequency(f_c)	3.4 GHz
Correlation (ρ)	1

This can be noticed that maximum gain is achieved at $\theta = 90^\circ$ and $\phi = 0^\circ$. These are the best values of elevation and azimuth angles to transfer maximum radiation.

2. Replication of FSS Earth Station Dish Antenna Pattern:

The Fixed Satellite Station (FSS) antenna is modeled according to [3]. It is kept fixed and also it does not depend on positions of Base Stations (BS). The FSS receiver thus always ensuring an LOS component of interference for the worst case. Table. II indicates the required parameters.

Table.II - Parameters used for AAS Pattern

Parameter	Value
Diameter (D)	4.8 meter
Direction	West
Carrier Frequency ($f_{c,fss}$)	3.9 GHz

Fig. III shows the polar plot of FSS Earth Station dish antenna. The FSS Earth Station antenna is placed in the center of annular ring, surrounded by Mobile Base Stations as shown in Fig. I

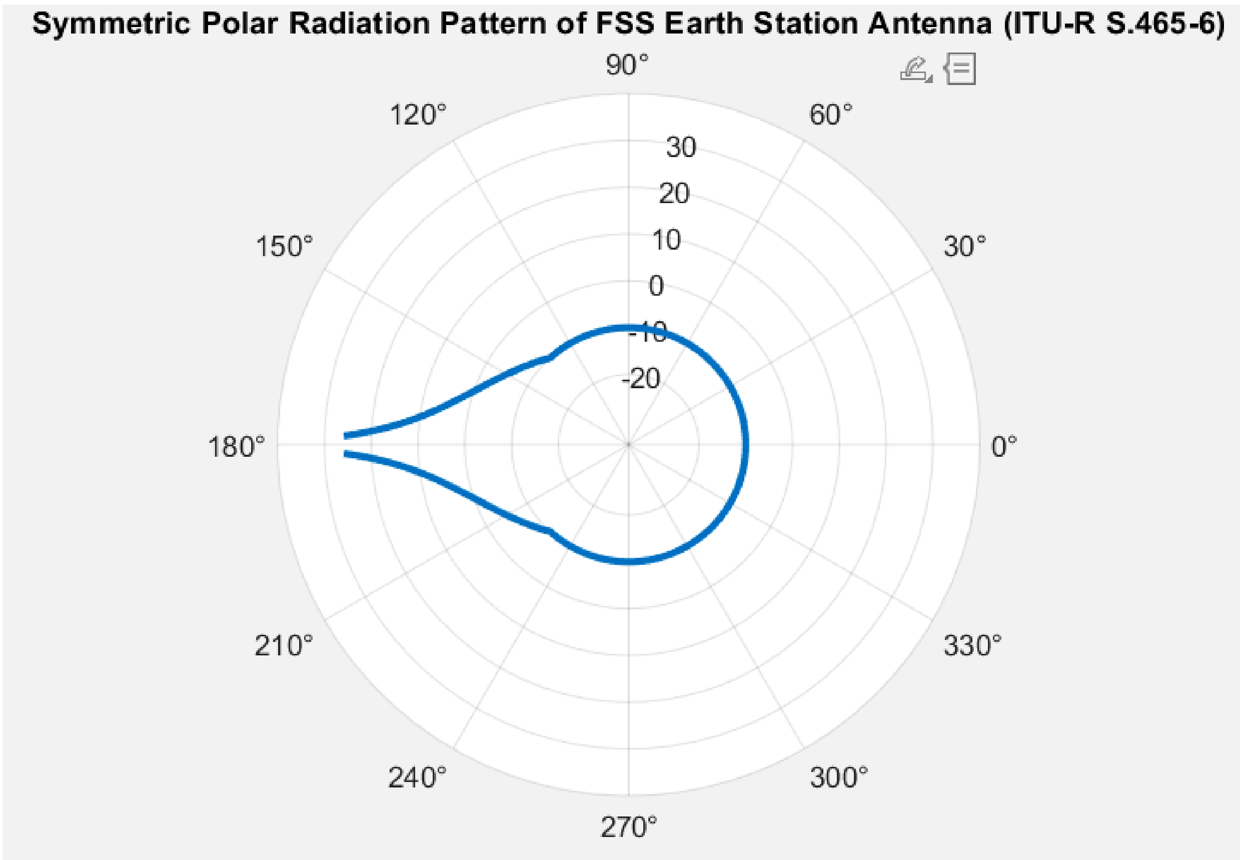


Fig. III

$$
\begin{aligned}
G &= 32 - 25 \log \varphi && \text{dBi} && \text{for } \varphi_{min} \leq \varphi < 48^\circ \\
&= -10 && \text{dBi} && \text{for } 48^\circ \leq \varphi \leq 180^\circ
\end{aligned}
$$

where:

φ_{min} = 1° or 100 λ/D degrees, whichever is the greater, for $D/\lambda \geq 50$.

φ_{min} = 2° or 114 $(D/\lambda)^{-1.09}$ degrees, whichever is the greater, for $D/\lambda < 50$.

This is the formula used to sketch the polar plot in MATLAB, which is referenced in [3].

3. Replication of FSS Earth Station Receiver Filter Response:

The FSS Earth Station Receiver filter is modeled according to Eq(1). The filter response is basically a square root raised cosine (SRRC) filter. Clearly, the filter attenuates the emission received for the OOB range, and passes the IB frequency range emission without any gain or attenuation. Fig.IV shows the bode plot of the filter. Basically the filter response is that of a high pass filter.

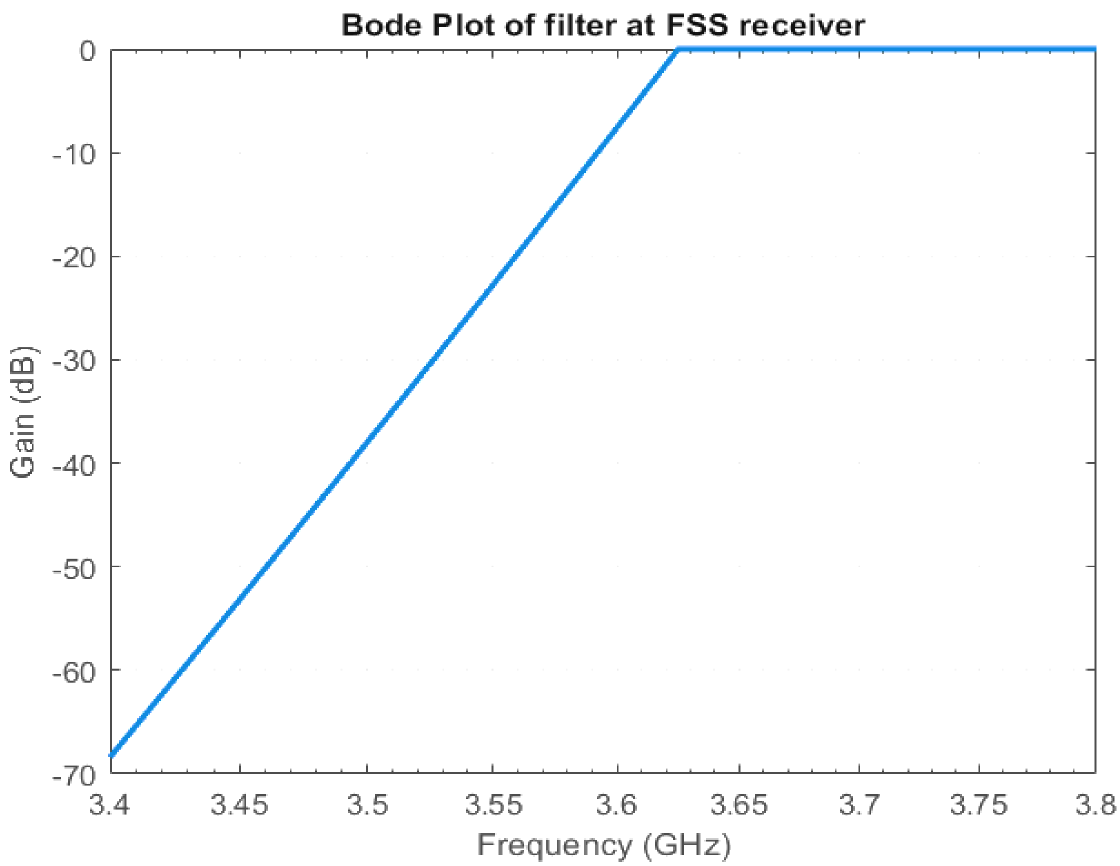
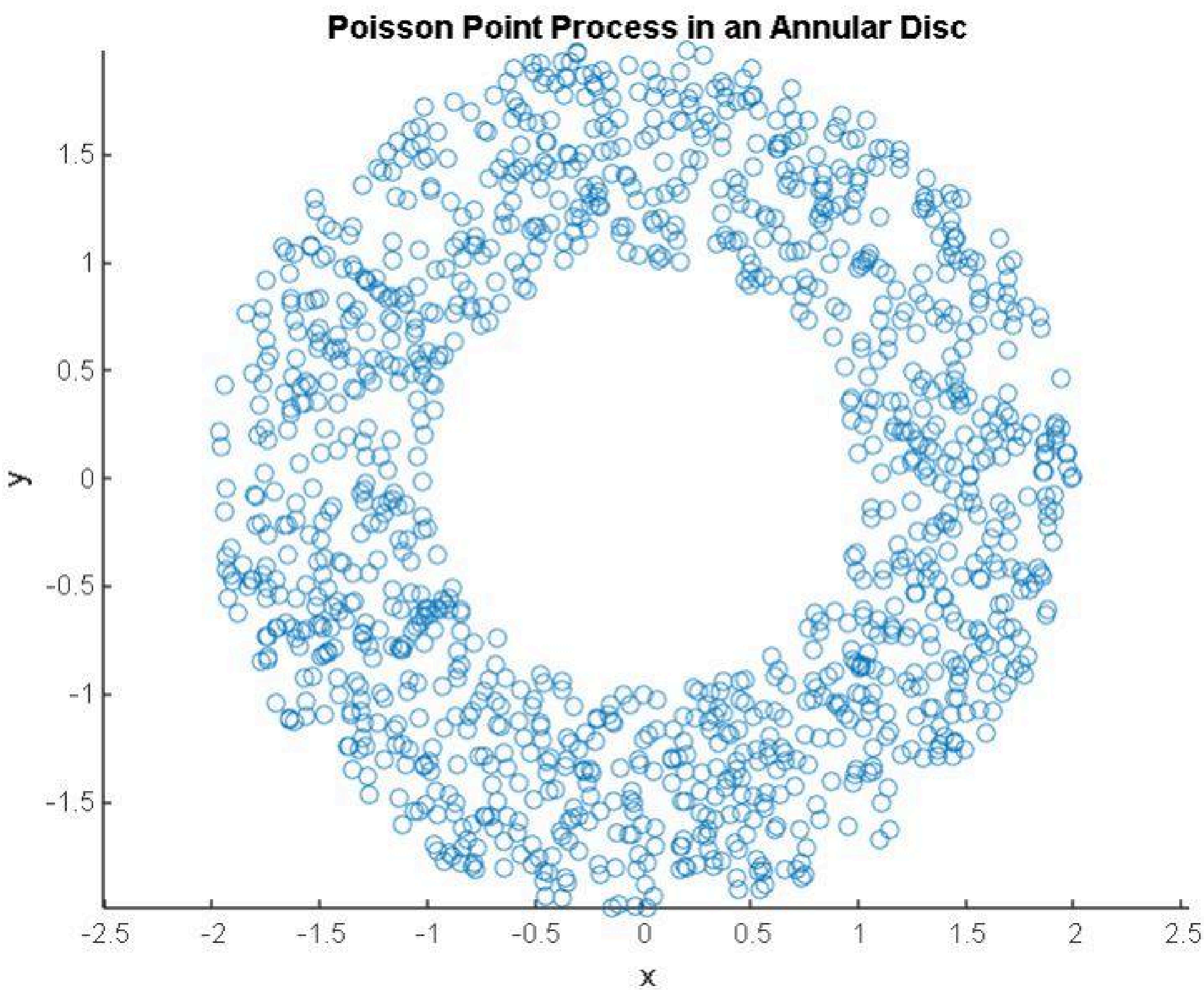


Fig. IV

4. Estimate deployment of cell towers using Monte Carlo simulation

We try to estimate the random deployment of 5g cellular base stations by changing the density of points in an annular disc like homogenous distribution and using Monte Carlo simulation to estimate the mean interference further.



5. Plotting interference vs mean density at centre of annular disc like distribution by power law path loss model

We try to check how accurate the model is by running simulations and comparing our observations with the theoretical model stated in [8]

Base stations (BSs) are randomly deployed in an infinite 2D space $\mathbb{R}^2$ and the PP $\Phi_{\mathrm{BS}} = \{\mathbf{X}_i, i \in \mathbb{N}\}$ denotes their locations. The sum interference at any point $\mathbf{y}$ is a random variable which can be written as the summation of signals from each BS attenuated according to the standard power-law path loss model, meaning that the received power attenuates with distance $r = \|\mathbf{x} - \mathbf{y}\|$ as $r^{-\alpha}$, thus

$$I = \sum_{\mathbf{X}_i \in \Phi_{\mathrm{BS}}} \frac{P_i}{\|\mathbf{X}_i - \mathbf{y}\|^{\alpha}}$$

For the case of a ring we take,

$$I_{\mathrm{A}} = \sum_{\mathbf{X}_i \in \Phi, a \le \|\mathbf{X}_i\| < b} \frac{p}{\|\mathbf{X}_i\|^{\alpha}} = \sum_{\mathbf{X}_i \in \Phi} \frac{p}{\|\mathbf{X}_i\|^{\alpha}} \mathbb{1}(a \le \|\mathbf{X}_i\| < b).$$

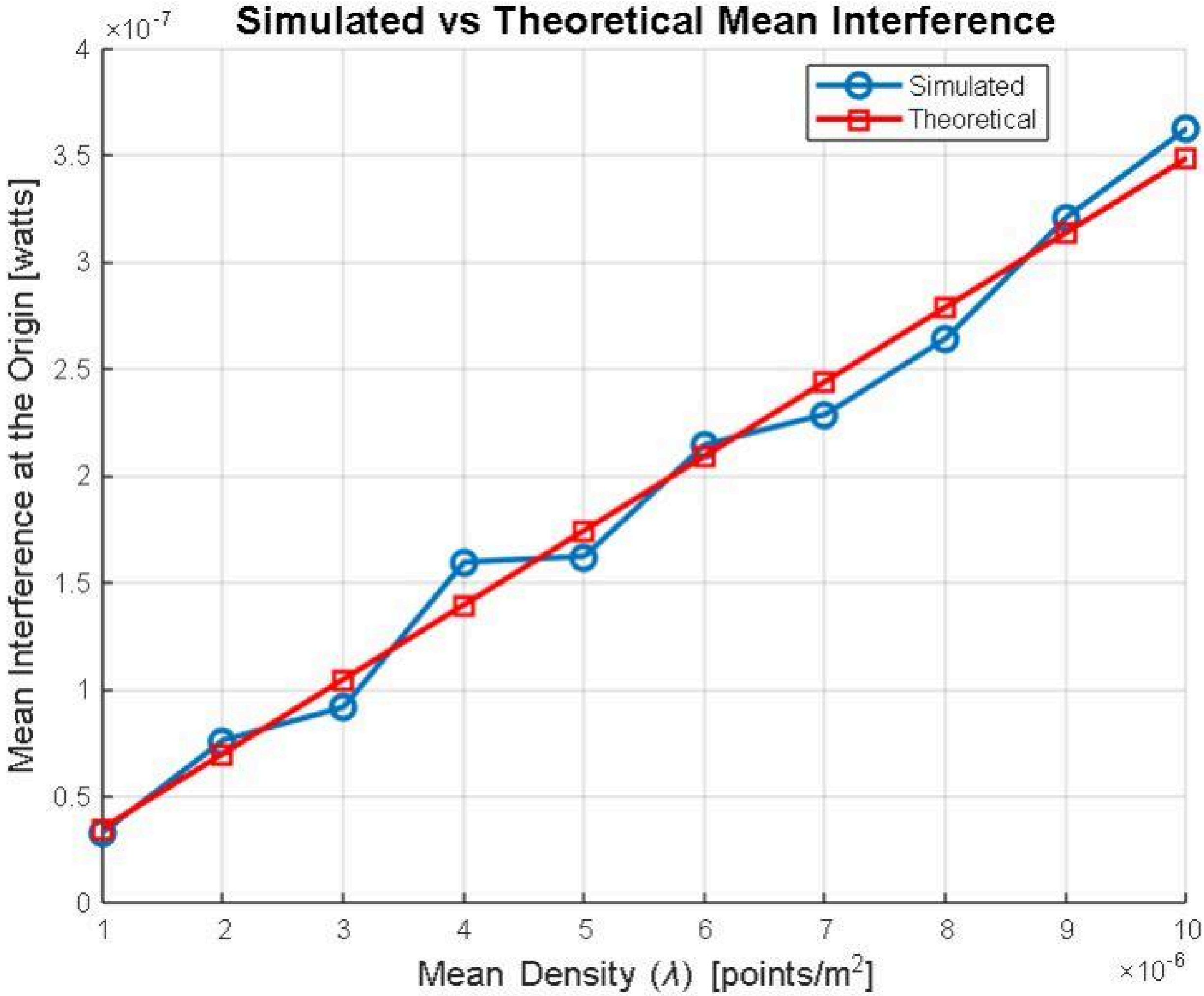
Thus,

Campbell's theorem can be usefully deployed to get the following expression:

$$\mathbb{E}[I_{\mathrm{A}}] = \mathbb{E}\left[\sum_{\mathbf{X}_i \in \Phi} \frac{p}{\|\mathbf{X}_i\|^{\alpha}} \mathbb{1}(a \le \|\mathbf{X}_i\| < b)\right] = \lambda \int_{\mathbb{R}^2} \frac{p}{\|\mathbf{x}\|^{\alpha}} \mathbb{1}(a \le \|\mathbf{x}\| < b) \mathrm{d}\mathbf{x}.$$

Using polar coordinates the mean interference is

$$\begin{aligned}
\mathbb{E}[I_{\mathrm{A}}] &= \lambda \int_0^{\infty} \int_0^{2\pi} \frac{p}{r^{\alpha}} \mathbb{1}(a \le r < b) \mathrm{d}\theta r \mathrm{d}r \\
&= 2\pi\lambda \int_a^b \frac{p}{r^{\alpha}} r \mathrm{d}r \\
&= \frac{2\pi\lambda p}{2-\alpha}\left(b^{2-\alpha} - a^{2-\alpha}\right) = \frac{2\pi\lambda p}{\alpha - 2}\left(\frac{1}{a^{\alpha-2}} - \frac{1}{b^{\alpha-2}}\right).
\end{aligned}$$



Here the annular disc is taken to be of
Inner radius- 30m
Outer radius -1000m
Transmitting power of 5g cellular base station- 10 watt

6. Plotting Pathloss vs Distance curve according to Recommendation ITU-R P.1546-6:

The Recommendation ITU-R P.1546-6 sets an empirical approach to calculate pathloss over distance. Basically, there are several plots of Electric Field strength and distance. From there we have chosen FIGURE 19 for land path and 1% time variability for 50% location variability and 2000 MHz frequency.

Now, we have introduced some correction factors as mentioned below

- Transmitting base antenna height correction using Eq.8 of the Recommendation ITU-R P.1546-6.
- Frequency correction (because we are concerned about C band i.e. 3400 MHz) using Eq.14 of Recommendation ITU-R P.1546-6.
- Receiving antenna height correction using Eq.28b of the Recommendation ITU-R P.1546-6.
- Location variability correction using Eq.34 of the Recommendation ITU-R P.1546-6.

Thereafter, we have applied some scenarios to plot Pathloss against distance. Table.III shows the scenarios.

Table.III - Simulation Scenarios

SIMULATION	PARAMETER
Simulation 1	ES = 30m, BS = 30m ES = 35m, BS = 30m
Simulation 2	ES = 30m, BS = 30m ES = 35m, BS = 30m Terrain Height Difference = 500m

Table.IV shows various common parameters required for the simulation.

Table.IV - Common Simulation Parameters

Height of BS	30 m
Time Variability	1%
Location Variability	1%
Frequency	3400 MHz
Propagation Path	Land

1) Simulation 1

A. ES = 30m. , BS = 30m.

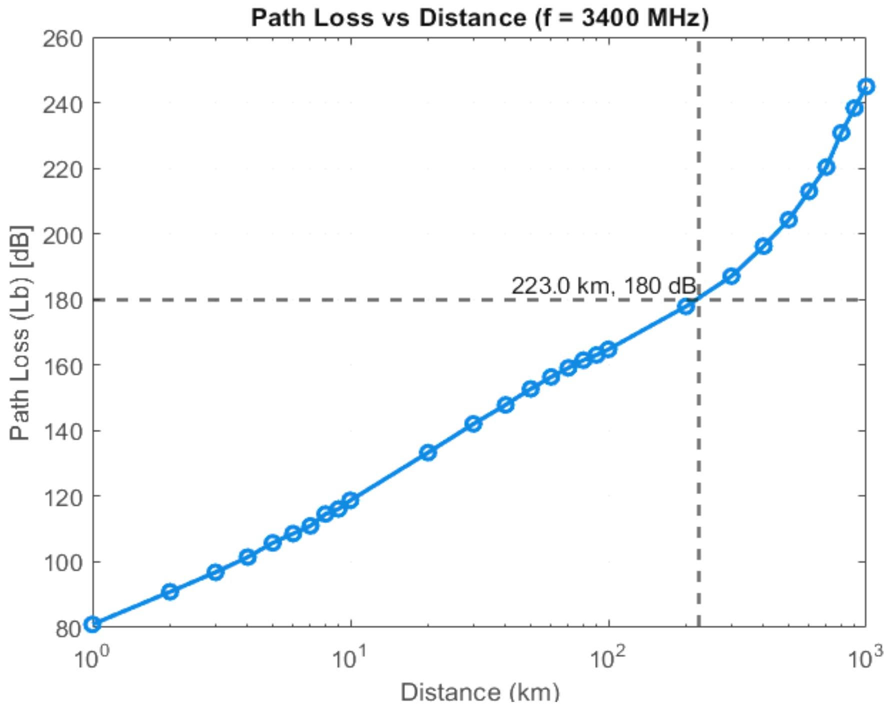


Fig. V

B. ES = 35m. , BS = 30m.

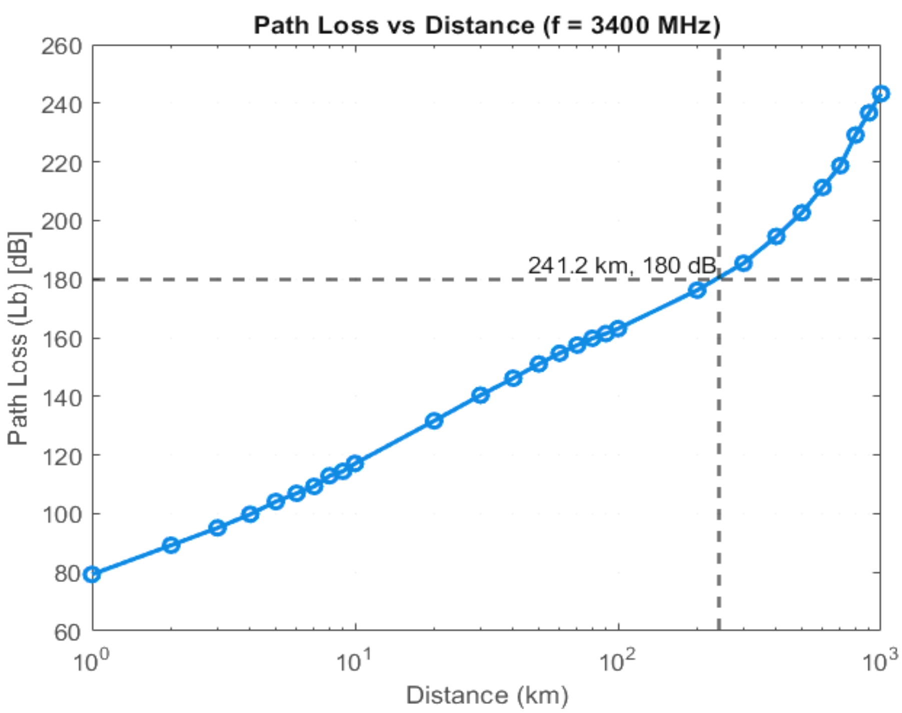


Fig. VI

2) Simulation 2

A. ES = 30m. , BS = 30m. , Terrain height difference = 500m.

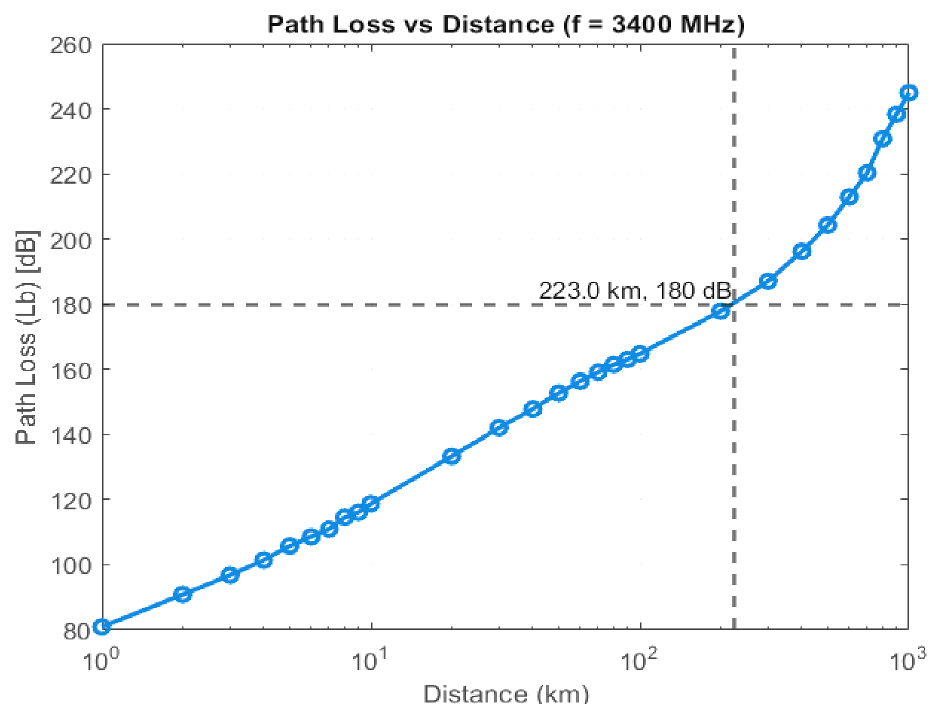


Fig. VII

B. ES = 35m. , BS = 30m. , Terrain height difference = 500m.

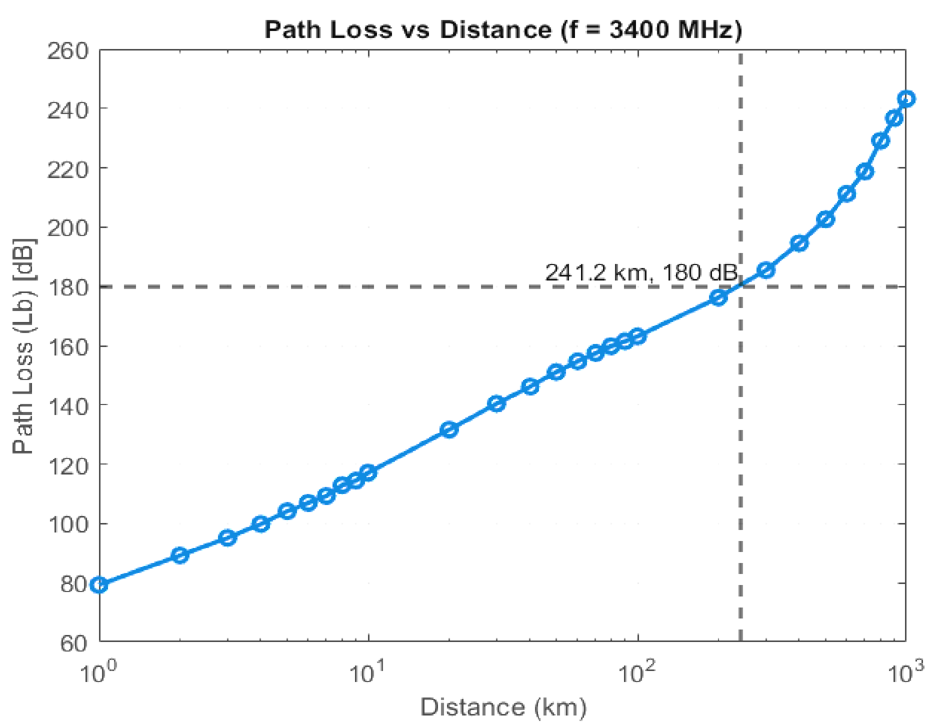
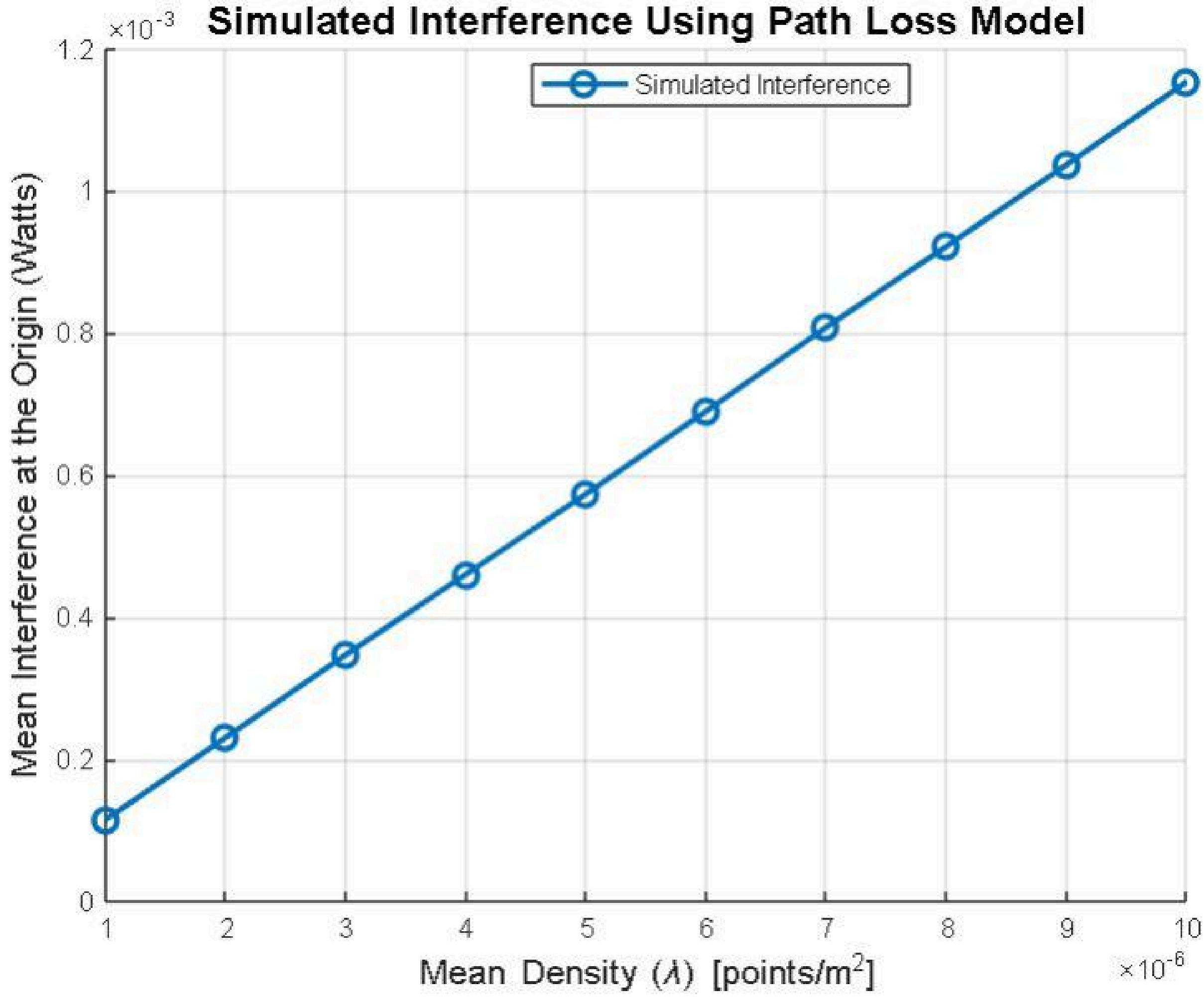


Fig. VIII

7.<u>Plotting interference vs mean density at centre of annular disc like distribution by using Recommendation ITU-R P.1546-6</u>

We use the above derived path loss model [4] in our earlier simulations of deployment of 5g cellular base stations in an annular ring and then comparing the results.



Here the annular disc is taken to be of
Inner radius- 30m
Outer radius -1000m
Transmitting power of 5g cellular base station- 10 watt

8. Getting Pathloss vs distance Curve and data for T-DUP model:

This is a non - deterministic model known as Tata Dense Urban Pathloss (T-DUP). For implementing this model, we have taken reference from [5]. It is also an empirical model to plot pathloss against distance. This model is limited to specific urban and sub-urban areas in Bangalore. Several operating parameters indulged in this method are given in Table. V.

Table. V - Operating Parameters

Operating Parameter	Value
BTS	18 dBi (65 deg azimuth)
Antenna Gain	15 dBi (90 deg azimuth)
Heights (h_{bs})	20 m
Transmission Power	20 W
Frequency Band (in MHz)	1800 MHz
Mobile Height	2 m
Roof Height (h_{roof})	3-storey Buildings with Height 9 m
Road Width (w)	20 m (DU), 6 m (DSU)
Building Separation (b)	0.001 - 0.01 m (U), 0.01 - 0.1 m (SU)
Avg. Drive test Speed	30 km/h

The equations used in this model are as follows to calculate the pathloss:

$$\begin{aligned} p_{LOS} &= \left(\frac{h_{bs} - h_{roof}}{h_{bs}}\right) \times \left(1 - \frac{d}{h_o}\right), \\ &= \frac{11}{20} \times \left(1 - \frac{d}{500}\right). \end{aligned}$$

…… Eq(2)

$$\begin{aligned} PL(dB)_{T-DUP} = &\Big\{ p_{los} \times 20 \log 10(f) \\ &+ (1 - p_{los}) \times \Big[20 \log 10(f) + 10 \log 10(f) \\ &+ 15\left(\frac{f}{925} - 1\right) \log 10(f) \Big] \Big\} \\ &+ \Big[30 \log 10(d) + K_a \log 10(w) + K_b \log 10(b) \\ &+ K_c \log 10(h_{bs}) + K_d \log 10(h_u) \Big]. \qquad \ldots \end{aligned}$$

…….Eq(3)

Fig. IX shows the obtained plot of pathloss against distance in an urban area of Bangalore with necessary parameters.

After various curve fitting iterations we have selected the statistical mean values: Ka= 10.944, Kb = −2.869, Kc = 6.633 and Kd = 7.164 as the most appropriate values specific to the areas considered in Bangalore.

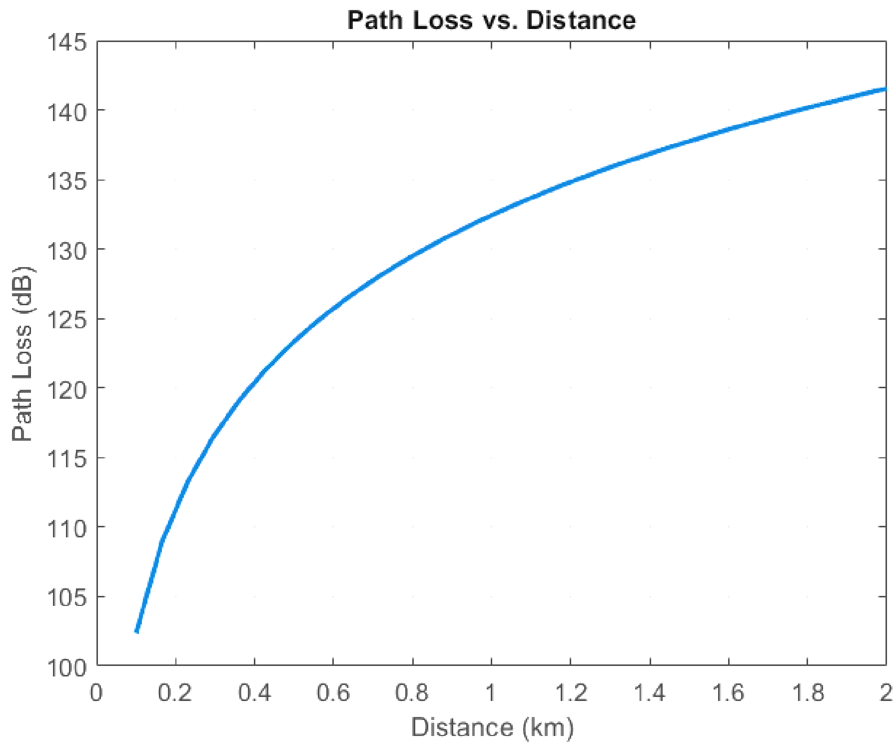


Fig. IX

9. Comparison of the various path loss model:

We have compared the three pathloss models :

1. Recommendation ITU-R P.452-18
2. T-DUP Model
3. Recommendation ITU-R P.1546-6

We have already explained the last two pathloss models. Recommendation ITU-R P.452-18 is referenced in [6]. According to it, the propagation loss is composed of free space pathloss given by Eq(4) and diffraction loss calculation mentioned in [7].

$$L_{FSPL} = 20.log_{10}(D) + 20.log_{10}(f_C) + 32.45 \quad \text{...... Eq(4)}$$

Table. VI shows various common parameters used to simulate comparison of these three models in C-band.

Table. VI - Common Parameters for simulation

Common terms	BS height(m)	ES height(m)	Frequency(MHz)	Terrain Height(m)
Recommendation ITU-R P.452-18	30	30	3400	20
TDUP Model	30	30	3400	20
Recommendation ITU-R P.1546-6	30	30	3400	20

Fig. X shows the comparison of pathloss against distance.

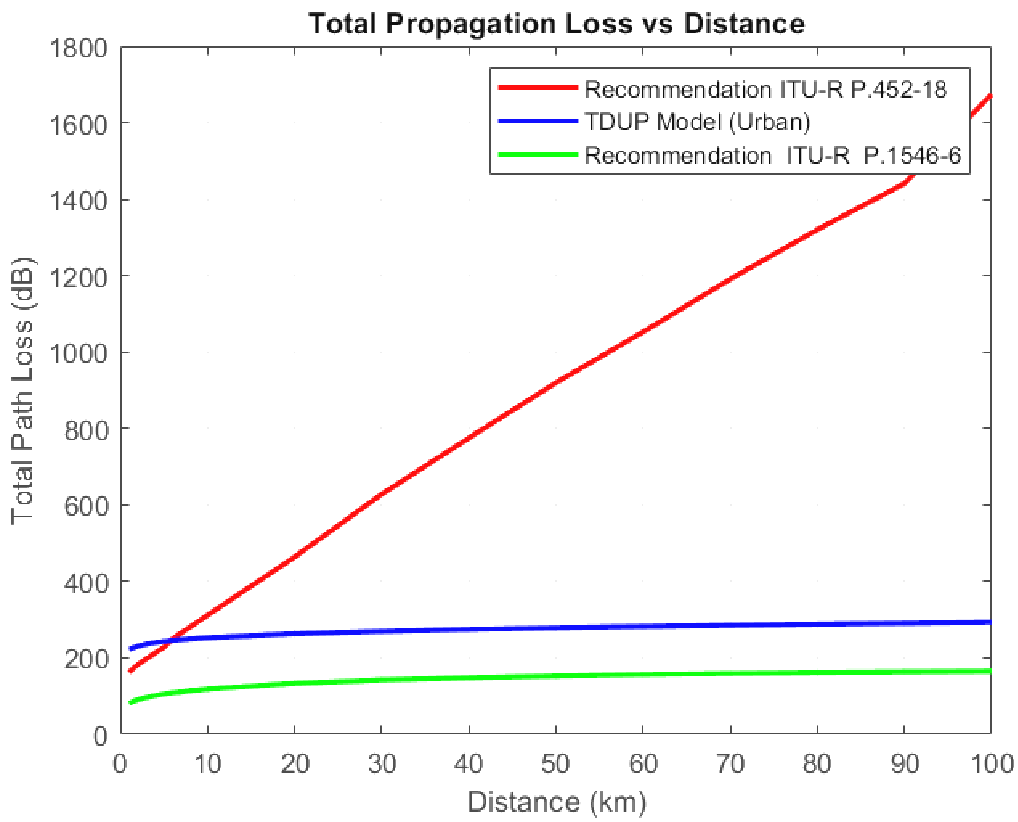


Fig. X

CONCLUSION AND FUTURE WORK

This work investigates the feasibility of coexistence between 5G cellular networks and Fixed Satellite Service (FSS) systems, focusing specifically on the normal mode forward link scenario in C band. Basically, we have discussed about different types of pathloss models. We have plotted Pathloss against distances of three specific models, keeping some of the parameters constant. We get the exposure as where to use a specific model. This in turn can help in the calculation of interference power. We are interested in Forward Link of FSS and Downlink of cellular Network.

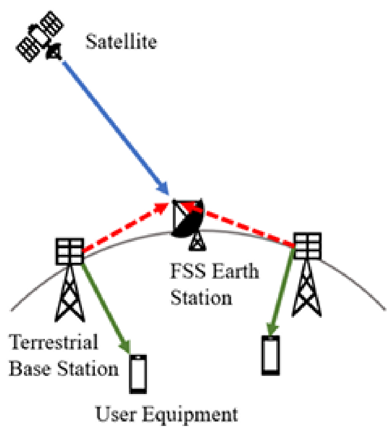


Fig. - XI

We also analyzed the antenna pattern of the Active Antenna System (AAS). We also plotted receiver filter response to see the nature of the filter.

In future this antenna pattern can be deployed in any model by changing the parameters to study interference between devices to minimize the interference level, which has a great scope. Our pathloss models are very dynamic in nature i.e. they can be adjusted for various scenarios and circumstances, which can be employed in other research works. One can explore dynamic spectrum access techniques to enhance coexistence efficiency and minimize interference. Exploring dynamic spectrum access techniques to enhance coexistence efficiency and minimize interference can also be done.

These directions aim to contribute toward sustainable coexistence solutions for next-generation wireless technologies and satellite services. The results provide valuable insights for stakeholders to develop strategies for efficient spectrum coexistence while ensuring minimal degradation of FSS performance.

REFERENCES

[1] A. I. Sulyman, A. T. Nassar, M. K. Samimi, G. R. Maccartney, T. S. Rappaport, and A. Alsanie, “Radio propagation path loss models for 5g cellular networks in the 28 ghz and 38 ghz millimeter wave bands,” IEEE Communications Magazine, vol. 52, no. 9, pp. 78–86, 2014.

[2] 3GPP TR 37.840 V12.1.0, “3rd generation partnership project; technical specification group radio access network; study of radio frequency (rf) and electromagnetic compatibility (emc) requirements for active antenna array system (aas) base station,” 3GPP, 2013.

[3] ITU-R S.465-6, “Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 ghz,” ITU, 2010

[4] "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz", *Recommendation ITU-R P.1546-6*.,2019.

[5] H. K. Rath, S. Verma, A. Simha and A. Karandikar, "Path Loss model for Indian terrain - empirical approach", *2016 Twenty-Second National Conference on Communication (NCC)*, vol. 10.1109, no. NCC.2016.7561183, pp. 1-6, 2016.

[6] E. Lagunas, C. G. Tsinos, S. K. Sharma and S. Chatzinotas, "5G Cellular and Fixed Satellite Service Spectrum Coexistence in C-Band," in IEEE Access, vol. 8, pp. 72078-72094, 2020.

[7] “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 100 MHz “, *Recommendation ITU-R P.452-18.,*2023.

[8] A Primer on Cellular Network Analysis Using Stochastic Geometry, April 2016,**Jeffrey G. Andrews** **Abhishek K. Gupta**,**Harpreet S. Dhillon**