A Project report submitted
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PROJECT NAME:

"CELLULAR NETWORK INFRASTRUCTURE VISUALIZATION IN INDIA"

BY:

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UNDER THE SUPERVISOR OF

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Acknowledgement:

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Project Scope:

Why Cell Tower Visualization is Important?

In a rapidly advancing digital world, mobile communication is vital for connectivity. Cell towers are the backbone of mobile networks, supporting services like calls, messaging, and internet access. Visualizing cell tower infrastructure in India offers valuable insights into the distribution and quality of network coverage, especially in diverse regions such as urban, semi-urban, and rural areas. Understanding this infrastructure is crucial for mobile network operators, policymakers, and consumers for various purposes:

- **Coverage Analysis**: Helps identify unprivileged areas where network expansion is needed.
- **Performance Optimization**: Provides data for optimizing existing infrastructure.
- **Policy Planning**: Assists government and regulatory bodies in allocating policies for equitable access.
- **Economic Planning**: Aids in understanding how infrastructure impacts local economies, especially in rural and underdeveloped areas.
- **Infrastructure Development**: Supports strategic decisions in developing new towers, especially with 5G rollouts.

Objectives of the Project:

The main objectives of this project are:

- To **visualize the distribution** of 3G, 4G, and 5G cell towers across India.
- To analyse **operator-based distributions** for major telecom companies: Airtel, Jio, and Vodafone.
- To **correlate the number of cell towers** with population density, household density, area, rural population density, rural household

density, rural area, household income annual and the presence of roads, highways, and residential infrastructure in Delhi.

- To understand the **relationship between cell tower proximity** and major highways and residential roads in state Delhi.
- To identify **regional disparities** in cell tower infrastructure and help inform decisions for future network development.

Stepwise Building of the Project:

a) Setting Up the Project Environment

The project uses a combination of technologies:

- **Flask Framework**: For the backend, enabling web-based visualization.
- **HTML, CSS and Leaflet JavaScript**: For interactive map visualization.
- **Folium Library**: A Python library that integrates with Leaflet to display geospatial data on a map.

b) Data Collection

I have collected the data from:

- **OpenCellID**: A comprehensive, open-source database of cell tower locations. Open Cell Id Website
- **Kaggle**: For additional datasets relevant to mobile network infrastructure. Kaggle mobile coverage data

c) Data Segmentation Based on Network Types

The cell tower data was divided based on the type of radio signals:

- **3G (UMTS)**
- **4G (LTE)**
- **5G (NR)**

This segmentation is essential because different technologies offer different coverage patterns and performance characteristics.

d) Operator Data Integration

The next step was to merge the cell tower data with operator data. I used a dataset that matched mobile network operators (Airtel, Jio, Vodafone) based on the **Mobile Network Code (MNC)** and **Mobile Country Code (MCC)**. The result was a more granular dataset showing which operator runs which towers.

e) Organizing Data by Operator

I created separate folders for each network type (3G, 4G, 5G), which contained:

- **3G_CSV**: Files for Airtel, Jio, and Vodafone cell towers, plus an "All Operators" file.
- Similarly, I created corresponding folders for **4G** and **5G** data.

f) Conversion to GeoJSON Format

GeoJSON format was used for the geospatial data as it integrates easily with web-based maps (Leaflet). Each dataset (3G, 4G, 5G) was converted into GeoJSON for better visualization and spatial analysis.

g) Indian Subdistrict GeoJSON Files

To enable analysis at the subdistrict level, I downloaded GeoJSON file for Indian subdistricts from **GitHub**. These files contained the geographical boundaries of each subdistrict. Git hub India

h) Merging GeoJSON Data

Using spatial operations like **inner join** and **within** functions, I merged the GeoJSON files containing the subdistrict boundaries with the cell tower data. This gave me a count of the number of cell towers (by operator and technology) in each subdistrict. This process was repeated for 3G, 4G, and 5G data and for each operator too.

I) Conversion to CSV

After the spatial analysis, the merged data was converted back to **CSV** format for further statistical analysis.

j) Area, Population Density, Household Density and Rural Metrics.

To explore correlations, I downloaded data from India official website (Census 2011) Census 2011 Data which has

- **Area** of each subdistrict.
- **Population density**, rural population, and household population and various other metrics.

k) Roads in Delhi GeoJson file.

I downloaded the road data from the hot export tool which is from Open Street Map. Hot export tool

l) Correlation Analysis

- I merged the subdistrict data with 3G, 4G, and 5G data and their operators to calculate metrics like the **number of cell towers per area**, **household density, % Rural population density, % Rural household density, % Rural Area** and various other metrics, and then find **correlation between cell towers and these above metrics**
- For road network analysis, I explored how the presence of highways impacts the number of cell towers in Delhi by using 1km by 1km grid.

m) Probability Distribution Analysis

Using **Cumulative Distribution Functions (CDF)**, I plotted the probability distribution of the nearest distance of cell towers to highways and residential roads in Delhi. This helped quantify the likelihood of finding a cell tower near a major road, offering insights into infrastructure planning along highways.

Analysis:

Correlation Analysis between various Metrics and Number of Cell Towers

Metrics	Radio	Operators	Correlation Value
	3G	Airtel	-0.002
		Jio	-0.047
		Vodafone	-0.018
		All operators	-0.004

Area	4G	Airtel	-0.037
		Jio	-0.012
		Vodafone	-0.043
		All operators	-0.02
	5G	Airtel	0.069
		Jio	-0.065
		Vodafone	NAN
		All operators	0.033
Population Density	3G	Airtel	0.685
		Jio	0.734
		Vodafone	0.775
		All operators	0.745
	4G	Airtel	0.659
		Jio	0.693
		Vodafone	0.594
		All operators	0.678
	5G	Airtel	0.657
		Jio	0.526
		Vodafone	0.911
		All operators	0.602
Household Density	3G	Airtel	0.708
		Jio	0.739
		Vodafone	0.784
		All operators	0.763
	4G	Airtel	0.685
		Jio	0.720
		Vodafone	0.615
		All operators	0.704
	5G	Airtel	0.642
		Jio	0.532
		Vodafone	0.845
		All operators	0.601
% Rural Population	3G	Airtel	-0.321
		Jio	-0.331
		Vodafone	-0.320
		All operators	-0.328
	4G	Airtel	-0.367
		Jio	-0.366
		Vodafone	-0.363
		All operators	-0.352
	5G	Airtel	-0.223
		Jio	-0.288
		Vodafone	-0.786
		All operators	-0.309
% Rural Household	3G	Airtel	-0.322
		Jio	-0.330
		Vodafone	-0.321
		All operators	-0.328
	4G	Airtel	-0.367
		Jio	-0.366
		Vodafone	-0.363
		All operators	-0.353
		Airtel	-0.222

	5G	Jio	-0.288
		Vodafone	-0.789
		All operators	-0.309
% Rural Area	3G	Airtel	-0.520
		Jio	-0.480
		Vodafone	-0.505
		All operators	-0.530
	4G	Airtel	-0.561
		Jio	-0.573
		Vodafone	-0.547
		All operators	-0.559
	5G	Airtel	-0.462
		Jio	-0.478
		Vodafone	-0.461
		All operators	-0.507
Household Income Annual	3G	Airtel	0.433
		Jio	0.426
		Vodafone	0.451
		All operators	0.443
	4G	Airtel	0.428
		Jio	0.447
		Vodafone	0.449
		All operators	0.442
	5G	Airtel	0.285
		Jio	0.412
		Vodafone	0.980
		All operators	0.412

Operator-Wise Analysis

1. **Area:** For Airtel, Jio, and Vodafone, there is no significant relationship between the number of cell towers and the area of subdistricts. **(-0.04 to 0.03)**
2. **Population and Household Density:** Airtel, Jio, and Vodafone all show a strong positive correlation with population and household density, indicating more cell towers per area in densely populated areas. **(0.6 to 0.8)**
3. **Rural Metrics**: The correlation is moderate negative for Airtel, Jio, and Vodafone, suggesting rural metrics has quite little impact on cell tower distribution. **(-0.3 to -0.6)**
4. **Household Income:** Airtel, Jio, and Vodafone all exhibit a moderate positive correlation with household income, indicating higher income areas tend to have more cell towers. **(0.4 to 0.5)**

Technology-Radio Wise Analysis

1. **Area:** There is no significant relationship between the number of cell towers and the area for 3G, 4G, or 5G technologies. **(-0.03 to 0.03)**
2. **Population and Household Density**: All technologies (3G, 4G, 5G) show a strong positive correlation with population and household density, indicating more towers in densely populated areas. **(0.6 to 0.8)**
3. **Rural Metrics**: The correlation is moderate negative for 3G, 4G, and 5G, suggesting rural metrics has quite little impact on tower distribution. **(-0.3 to -0.6)**
4. **Household Income**: 3G, 4G, and 5G all show a moderate positive correlation with household income, indicating that higher income areas tend to have more cell towers. **(0.4 to 0.5)**

Summary:

- **Population Density and Household Density** have a strong positive correlation with the number of cell towers across all technologies, indicating that higher density areas tend to have better coverage.
- **Area and Rural Metrics** generally show moderate negative correlations, suggesting that the size of the area and rural characteristics have impact on the distribution of cell towers.
- **Household Income** consistently shows a moderate positive correlation with the number of cell towers, indicating that higher income areas are more likely to have better network infrastructure.

Correlation Grid Analysis of Cell Tower Distribution with Highway and Residential Road Presence in Delhi: "A Pipeline Approach":

Cell Towers	Road Types	Correlation Value
3G	Highways	0.448
	Residential	0.289
	Residential and Highways	0.314
4G	Highways	0.434
	Residential	0.291
	Residential and Highways	0.300

The analysis shows that both 3G and 4G cell towers have a moderate positive correlation with highways. This indicates that these towers are more likely to be located near highways. The correlation with residential roads is weaker, suggesting that while there is some association, it is not as strong as with highways. The presence of both residential and highways shows a moderate positive relationship for both types of cell towers.

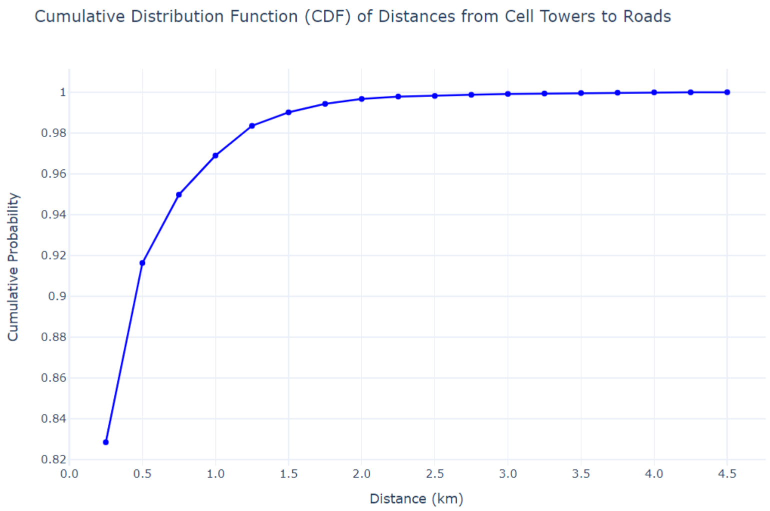
These findings highlight the importance of highways in the placement of cell towers, likely due to the higher traffic and connectivity that highways provide. The three main reasons are:-

- **Higher Traffic**: Highways support more traffic and provide vital connectivity, making them prime locations for cell towers to serve a larger number of users effectively.
- **Network Efficiency**: Placing towers along highways enhances network coverage and efficiency, allowing operators to cover extensive areas with fewer towers.
- **Infrastructure**: Highways typically have better infrastructure and accessibility for installing and maintaining cell towers, including existing utility lines and access roads, which simplifies the process.

This analysis provides valuable insights into how infrastructure influences cell tower distribution, which can be useful for planning and optimizing network coverage in Delhi.

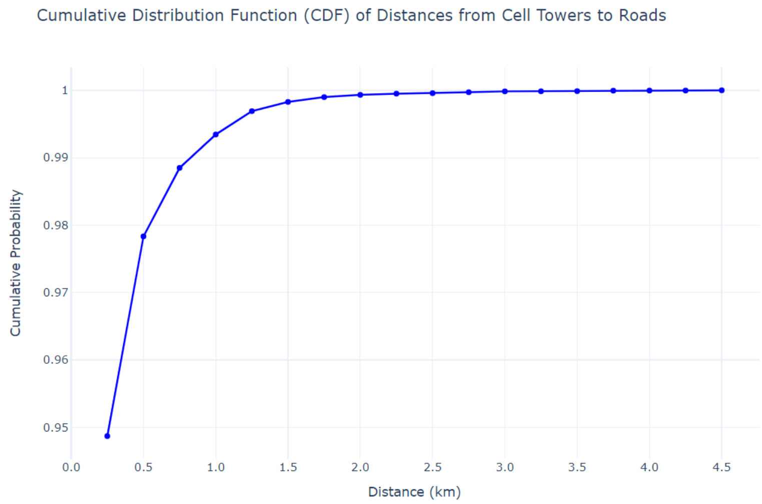
Probability distribution Analysis using CDF to plot the nearest distance of Cell Towers to Roads in Delhi:

3G to Highways Roads



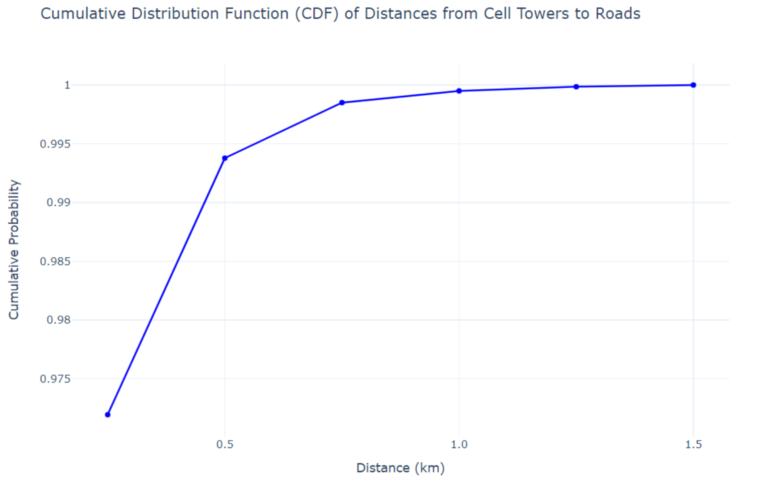
Over 96% of 3G cell towers are within 1km distance to nearest highway.

3G to Residential Roads



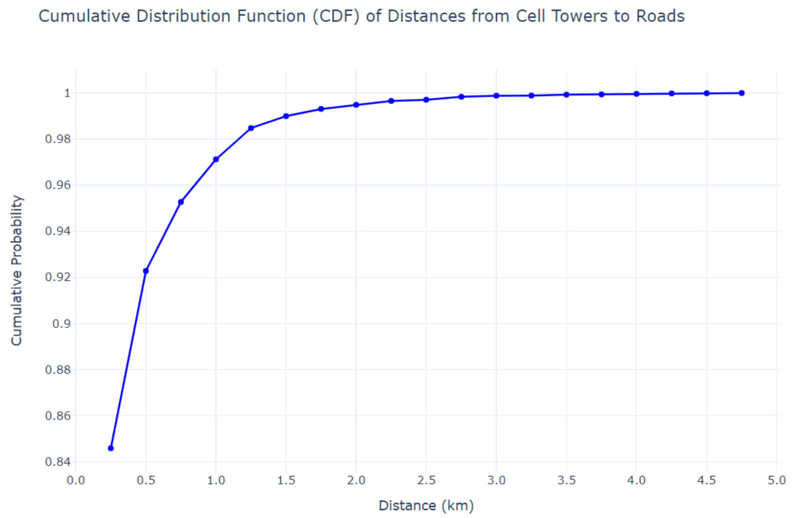
Over 99% of 3G cell towers are within 1km distance to nearest residential roads

3G to Residential and Highway Roads



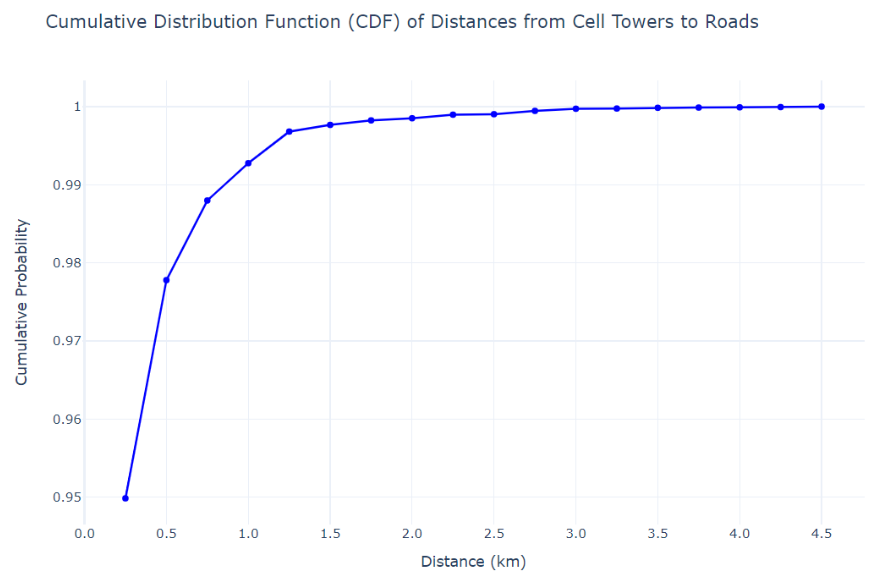
Over 99.9% of 3G cell towers are within 1km distance to nearest residential and highway.

4G to Highway Roads



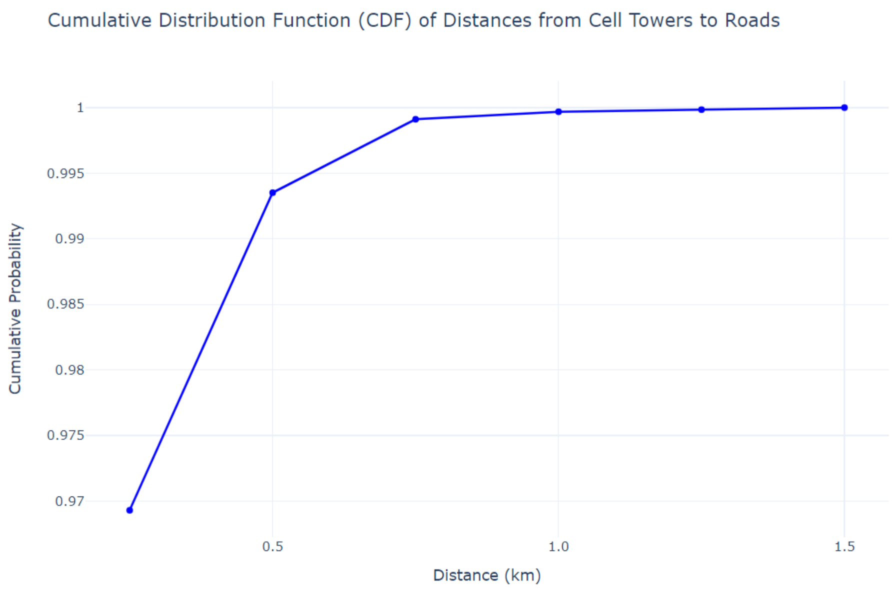
Over 97% of 4G cell towers are within 1km distance to nearest highway.

4G to Residential Roads



Over 99% of 4G cell towers are within 1km distance to nearest residential roads.

4G to Residential and Highway Roads



Over 99.9% of 4G cell towers are within 1km distance to nearest residential and highway.

Skills Learned:

Throughout this project, I developed the following skills:

- **Data Cleaning/preprocessing**: Efficiently organizing and cleaning large datasets.
- **Spatial Analysis**: Working with GeoJSON and CSV formats to analyse geospatial relationships.
- **Map Visualization**: Creating interactive maps with **Leaflet.js** and **Folium**.
- **Web Development**: Utilizing the **Flask** framework to build a web-based data visualization platform.
- **Correlation Analysis**: Using statistical methods to explore relationships between cell tower data and external factors like population density and road proximity.

Limitations of the Project:

Despite the detailed analysis, several limitations were encountered:

- **Data Incompleteness**: OpenCellID may not have complete data for all regions, especially in rural or remote areas.
- **Coverage Bias**: The analysis may be biased toward areas with better data reporting, such as urban centres.
- **Static Data**: The data used is a snapshot in time, which does not account for real-time changes or upgrades in infrastructure.
- **5G Data** : There are only around 2700 5G Cell towers in India. This shows the data is limited which might show incorrect correlation between metrics and number of cell towers.

Conclusion:

This project provides a detailed visualization of cell tower network infrastructure in India across 3G, 4G, and 5G technologies. By mapping and analysing the distribution of cell towers based on operators, population density, and road networks, we gain valuable insights into the state of mobile network coverage in India. The findings can inform future infrastructure development, especially in underserved areas, and aid network operators in optimizing coverage. However, continuous updates and real-time data are needed to maintain the accuracy of such analyses, particularly as 5G technology matures.

This project demonstrates how geospatial data and visualization tools can provide meaningful insights into network infrastructure, ultimately supporting improved connectivity across India.