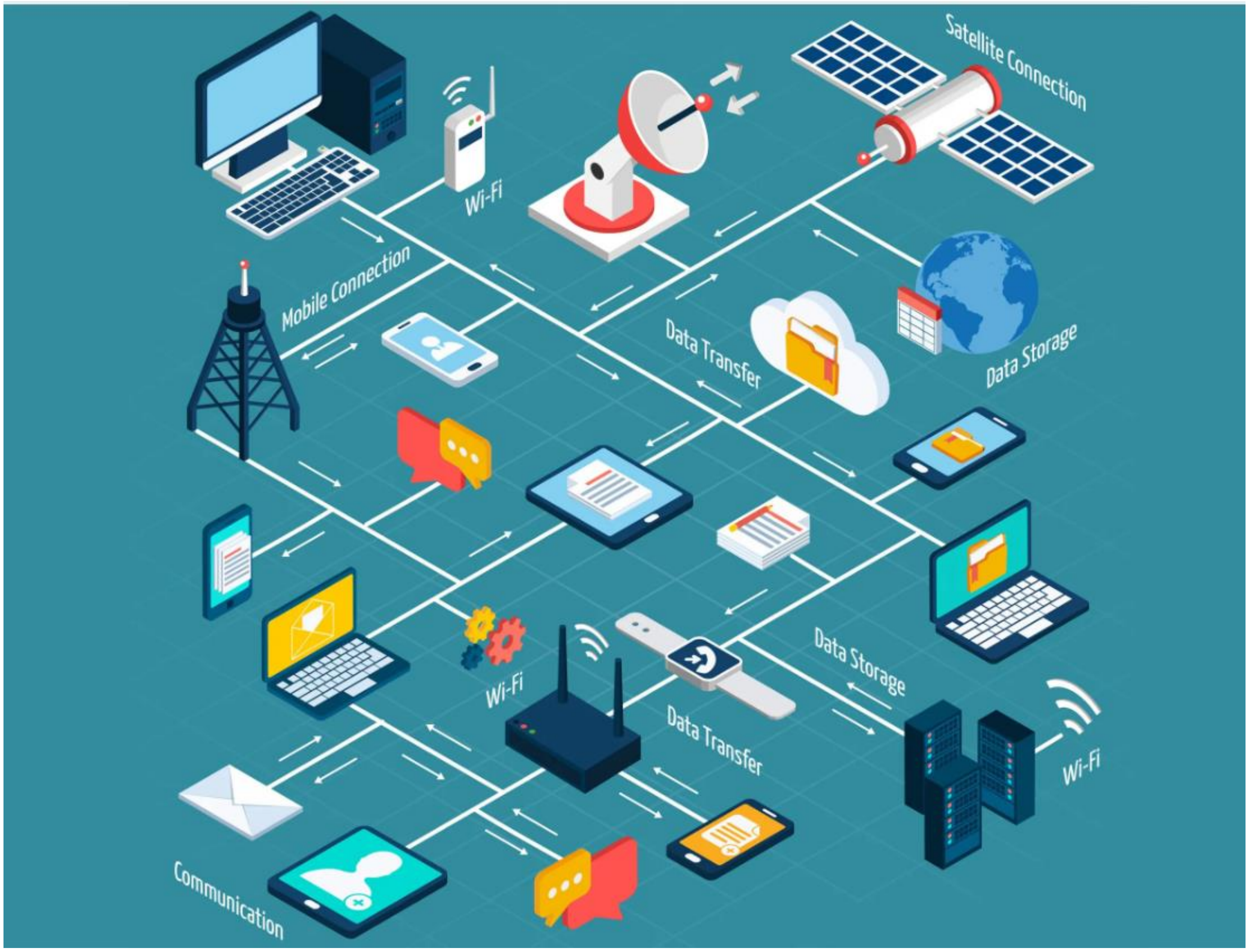

Wireless Communication Project Report

ECE 353

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Part A

1. Omni Case

- **Hand Analysis:**

Test Case ①:

Gos = 0.02 in decimals

City Area = 400 Km^2

user density = 2000 $\frac{user}{Km^2}$

SIR_{Min} = 15 dB

Sectorization = omni

$S = 340$

traffic/user = 0.025

$n = 4$

$$\boxed{SIR_{min\ ratio} = \frac{1}{6}\left[\sqrt{3N} - 1\right]^n}$$

$$10^{1.5} = \frac{1}{6}\left[\sqrt{3N} - 1\right]^4$$

$$\boxed{N = 9}$$

$K = \frac{S}{N} = 37$ channel/cell

from table

Traffic / cell = 28.3 Erlang

$$\boxed{\text{Total traffic} = \text{user density} \times \text{Area} \times \text{traffic/user}}$$

$= 20\,000$ Erlang

$$\boxed{\text{No. of cells} = \frac{\text{total traffic}}{\text{traffic / cell}}} = 707 \text{ cell}$$

Area of system $= 707 \times \frac{1}{2} \times \frac{\sqrt{3}}{2} \times R_i^2 6$

$R = 466.65$ m

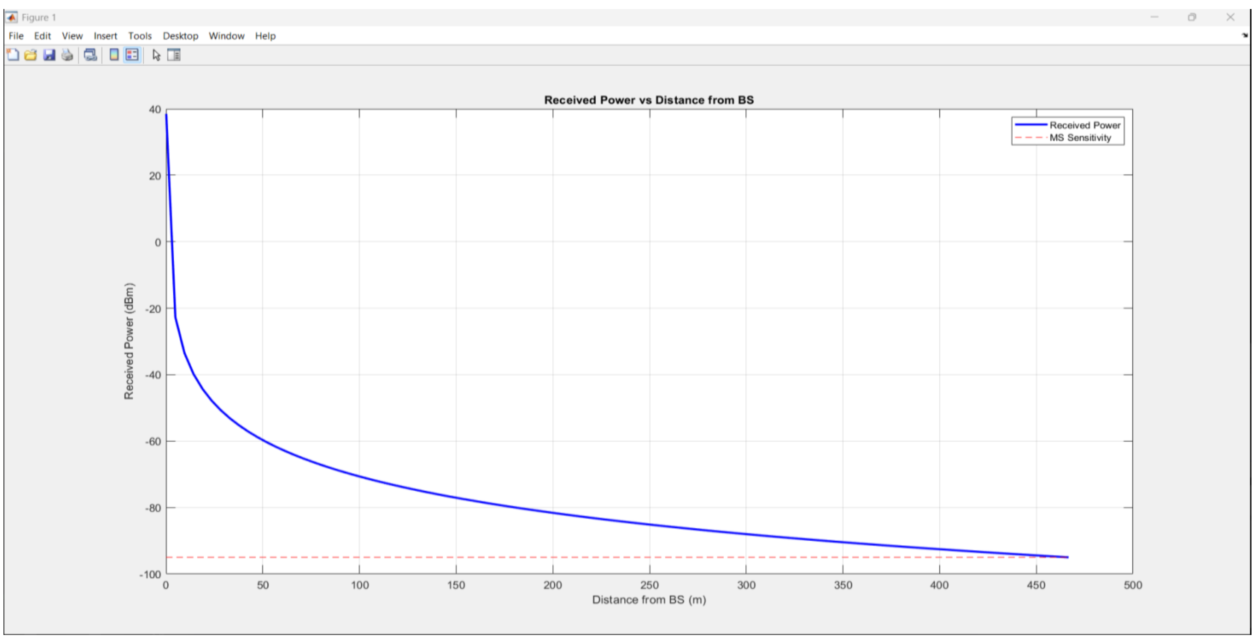
- **Transcript:**

Command Window

```
>> Interpolation
=== Cellular Network Planning Tool ===
Enter Grade of Service (GOS) as decimal (e.g., 0.02): 0.02
Enter city area in km²: 400
Enter user density in users/km²: 2000
Enter minimum SIR in dB: 15
Enter sectorization method (omni/60/120): omni

1) Cluster Size (N): 9
2) Total number of cells in city: 707
3) Cell radius: 466.65 meters
4) Traffic intensity per cell: 28.29 Erlang
   Maximum supported traffic per cell: 28.30 Erlang
5) Base station transmitted power: 21.80 dBm
```

- **Result:**



2. "60" Sectorization Case:

- **Hand Analysis:**

Test Case ②:

- Sectorization = 60°

Gos = 0.02 in decimals

City Area = 400 Km^2

user density = 2000 $\frac{user}{Km^2}$

SIR_{min} = 15 dB

$$SIR_{min\ ratio} = \frac{1}{1}\left[\sqrt{3N}-1\right]^n$$

$$10^{1.5} = \left[\sqrt{3N}-1\right]^4$$

$N = 4$ ①

$K = \frac{340}{4} = 85$ channel , channel per sector = $\frac{\text{channel / cell}}{\text{no. of sector}}$

$\boxed{\text{Channel per sector} = 14 \text{ channel}}$

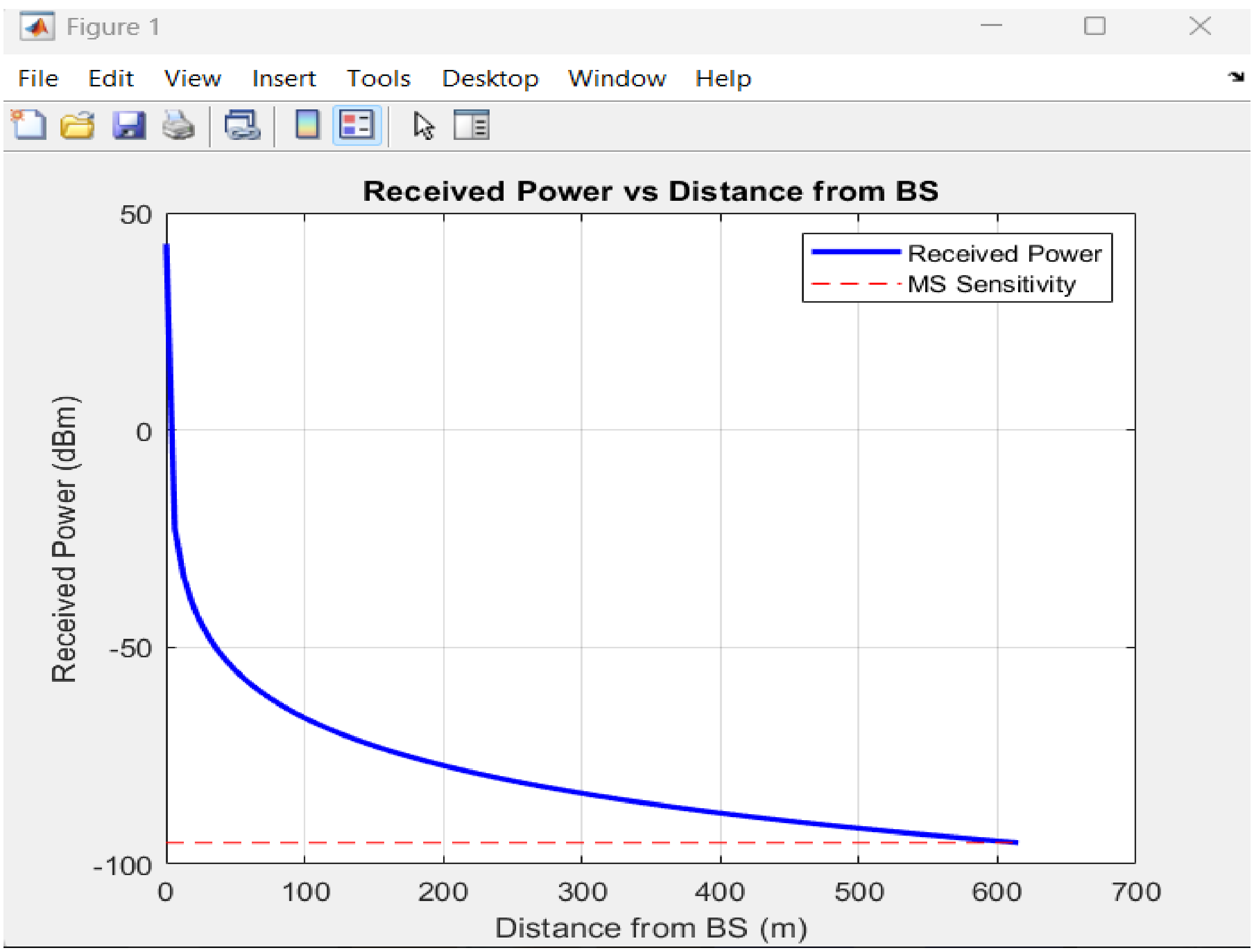
- traffic per sector = 8.2 Erlang
- traffic per cell = 6×8.2 = 49.2 Erlang
- Total Traffic = 20 000 Erlang
- No. of cells = $\frac{\text{Total traffic}}{\text{traffic/cell}}$ = 406 cell
- $400 = 406 \times \frac{1}{2} \times \frac{\sqrt{3}}{2} \times R^2 \times 6$
- R = 615.42 m

- **Transcript:**

```
=== Cellular Network Planning Tool ===
Enter Grade of Service (GOS) as decimal (e.g., 0.02): 0.02
Enter city area in km²: 400
Enter user density in users/km²: 2000
Enter minimum SIR in dB: 15
Enter sectorization method (omni/60/120): 60

1) Cluster Size (N): 4
2) Total number of cells in city: 407
3) Cell radius: 615.04 meters
4) Traffic intensity per cell: 49.14 Erlang
   Traffic intensity per sector: 8.19 Erlang
   Maximum supported traffic per sector: 8.20 Erlang
5) Base station transmitted power: 26.16 dBm
fx >>
```

- **Result:**



3. “120” Sectorization Case:

- **Hand Analysis:**

Test Case (3):

GoS = 0.02 in decimals

Area = 400

User density = 2000

SIR Min = 15dB

Sectorization = 120

$$10^{1.5} = \frac{1}{2}\left[\sqrt{3N} - 1\right]^4$$

$N = 7$

$K = \frac{340}{7} = 48$ Channel/cell

Channel per sector = 16 channel per sector

traffic / sector = 9.83

traffic per cell = 3 x 9.83 = 29.5

Total traffic = 20000

No. of cell = $\frac{\text{Total traffic}}{\text{Traffic per cell}} = \frac{20000}{29.5} = 679$ cell

Area of system $= 679 \times \frac{1}{2} \times \frac{\sqrt{3}}{2} \times R^2 \times 6$

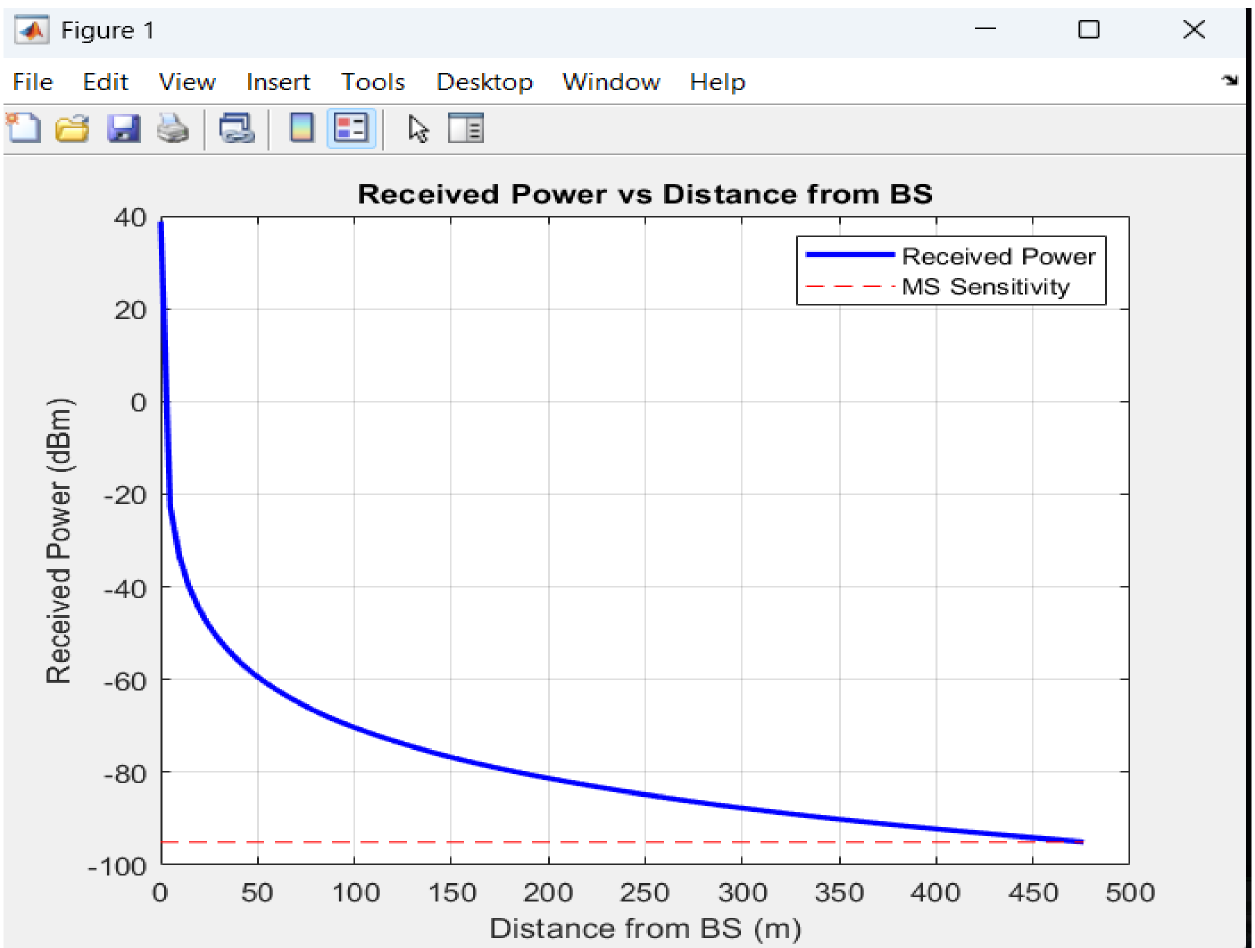
$R = 476.17m$

- **Transcript:**

```
Command Window
=== Cellular Network Planning Tool ===
Enter Grade of Service (GOS) as decimal (e.g., 0.02): 0.02
Enter city area in km²: 400
Enter user density in users/km²: 2000
Enter minimum SIR in dB: 15
Enter sectorization method (omni/60/120): 120

1) Cluster Size (N): 7
2) Total number of cells in city: 679
3) Cell radius: 476.18 meters
4) Traffic intensity per cell: 29.46 Erlang
   Traffic intensity per sector: 9.82 Erlang
   Maximum supported traffic per sector: 9.83 Erlang
5) Base station transmitted power: 22.11 dBm
fx >>
```

- **Result:**



4. Out of range Case:

- **Hand Analysis:**

$GOS = 0.04$

$Area = 400$

user density $= 2000$

$SIR = 18$

$$10^{1.8} = \frac{1}{6}\left[\sqrt{3N} - 1\right]^4$$

$N = 12$

$$K = \frac{340}{12} = 28 \text{ channel/cell}$$

traffic/cell $= 22.05$

Total traffic $= 20000$ erlang

$$N\,cell = \frac{20000}{22.05} = 907 \text{ cell}$$

Area

$$400 = 907 \times \frac{1}{2} \times \frac{\sqrt{3}}{2} \times 6 \times R^2$$

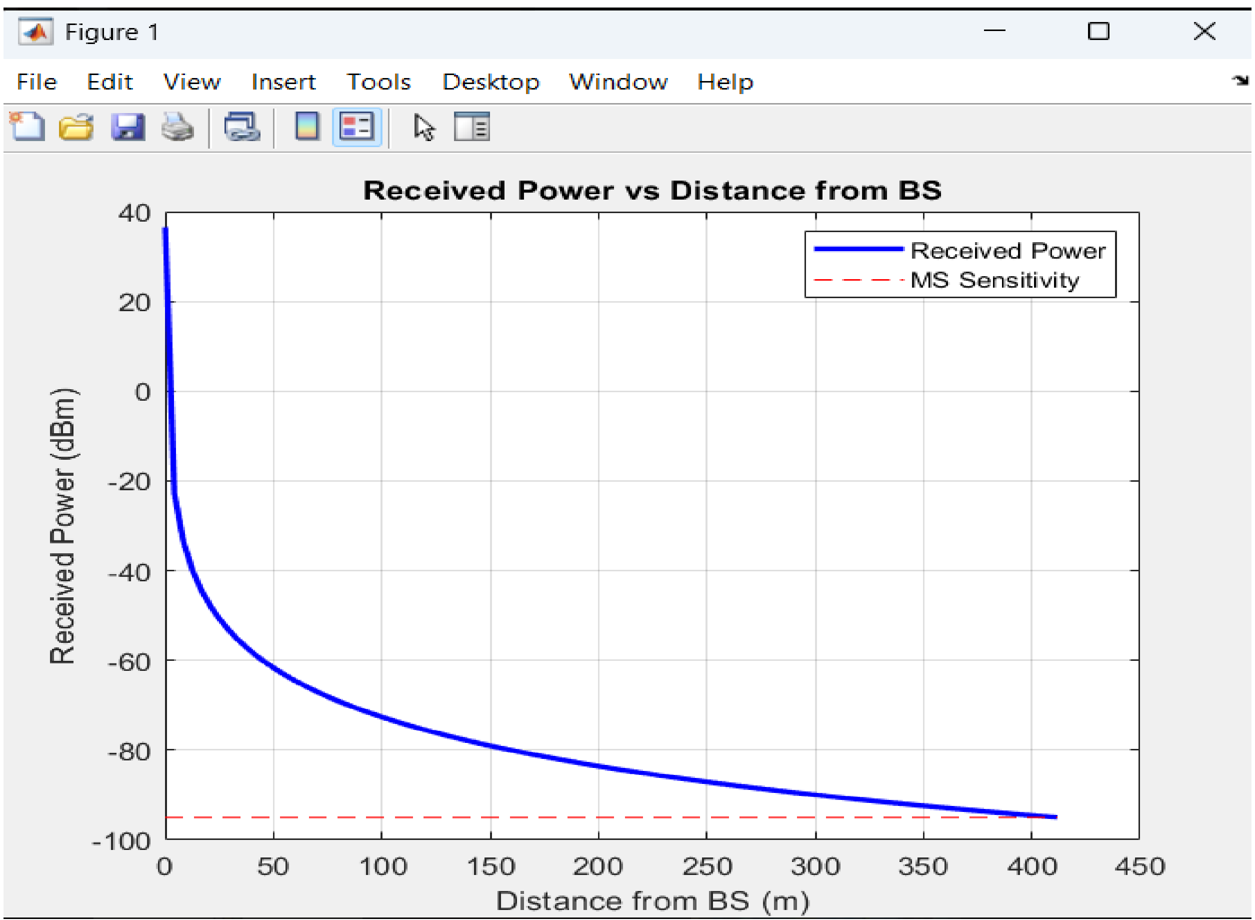
$412\ m = R$

- **Transcript:**

```
Command Window
=== Cellular Network Planning Tool ===
Enter Grade of Service (GOS) as decimal (e.g., 0.02): 0.04
Enter city area in km²: 400
Enter user density in users/km²: 2000
Enter minimum SIR in dB: 18
Enter sectorization method (omni/60/120): omni

1) Cluster Size (N): 12
2) Total number of cells in city: 908
3) Cell radius: 411.78 meters
4) Traffic intensity per cell: 22.03 Erlang
   Maximum supported traffic per cell: 22.05 Erlang
5) Base station transmitted power: 19.82 dBm
fx >>
```

- **Result:**



Code Explanation:

1. Input Parameters

The tool collects the following **user inputs**:

- **GOS (Grade of Service):**
  Desired call blocking probability (e.g., `0.02` for 2%)
- **City Area:**
  Total area to be covered (in km^2)
- **User Density:**
  Number of users per km^2
- **SIR_min:**
  Minimum required Signal-to-Interference Ratio (in dB)
- **Sectorization Method:**
  Antenna configuration type:
  - `'omni'`: Omnidirectional
  - `'60'`: 6-sector
  - `'120'`: 3-sector

2. Cases Implemented:

1. Omnidirectional (Omni) Case

- **Characteristics:**
  Single antenna covers **360°**
- **Impact on Calculations:**
  - All **channels are shared** across the cell's full coverage
  - **Higher interference** from neighboring cells ⇒ **Lower SIR**
  - Typically requires **larger cluster sizes (N)** to meet SIR
  - Simplified infrastructure, but with **lower capacity**
  - Results in **less efficient frequency reuse**

2. 60° Sectorization (6 Sectors) Case

- **Characteristics:**
  6 directional antennas per cell, each covering a **60°** sector
- **Impact on Calculations:**
  - Channels are **divided among 6 sectors**
  - Directional antennas lead to **reduced interference** ⇒ **Higher SIR**
  - Enables **smaller cluster sizes (N)**
  - Allows for **higher capacity**
  - **Better frequency reuse** but with **increased infrastructure complexity**
  - Requires **more precise network planning and alignment**

3. 120° Sectorization (3 Sectors) Case

- **Characteristics:**
  3 directional antennas per cell, each covering a **120°** sector
- **Impact on Calculations:**
  - Channels are **divided among 3 sectors**
  - Offers a **moderate reduction in interference**
  - Typical cluster size falls **between omni and 60°** sectorization
  - Balances **capacity and complexity**
  - Considered the **most commonly used configuration** in practice

3. Constants and Erlang B Table

The tool includes:

- **Fixed Parameters** for system assumptions
- **Erlang B Table**:
  - Rows: Number of channels
  - Columns: GOS values
  - Values: Maximum supported traffic (in Erlangs)

4. Key Calculations

a) Cluster Size (N) Calculation

- Performed using `calculate_cluster_size()` function
- Selects smallest standard cluster size (e.g., 1, 3, 4, 7, 9...) that satisfies SIR_min
- SIR calculation differs by sectorization method:
  - **Omni-directional**
  - **3-sector (120°)**
  - **6-sector (60°)**

b) Channel Distribution

- Total channels = **340**
- Calculates:
  - **Channels per cell**
  - **Channels per sector** (if applicable)
- Based on:
  - Selected **cluster size (N)**
  - **Sectorization method**

c) Traffic Capacity

- Uses **Erlang B Table** to:
    - Find maximum supported traffic per sector/cell
    - Perform **interpolation** if exact GOS not listed
- Assumes **0.025 Erlang per user** to compute:
    - **Max number of users per cell**

d) Cell Count and Radius

- Determines:
    - **Total number of cells needed** to serve all users
    - **Cell radius**, using **hexagonal cell area** formula

e) Base Station Transmit Power

- Uses **Hata model** (urban, medium city) to compute:
    - Path loss
    - Required **transmit power** to achieve **-95 dBm** at cell edge
- Assumptions:
    - Frequency = **900 MHz**
    - BS height = **20 m**
    - MS height = **1.5 m**
    - Path loss exponent = **4**

5. Output Results

The tool displays:

- **Cluster size (N)**
- **Total number of required cells**
- **Cell radius** (in meters)
- **Traffic intensity per cell and per sector**
- **Base station transmit power** (in dBm)
- **Plot of received power vs. distance**

Key Functions

`calculate_cluster_size()`

- Core function to determine optimal **cluster size**
- Iterates through standard cluster sizes
- Uses: **Different SIR formulas** depending on sectorization

Hata Model Implementation

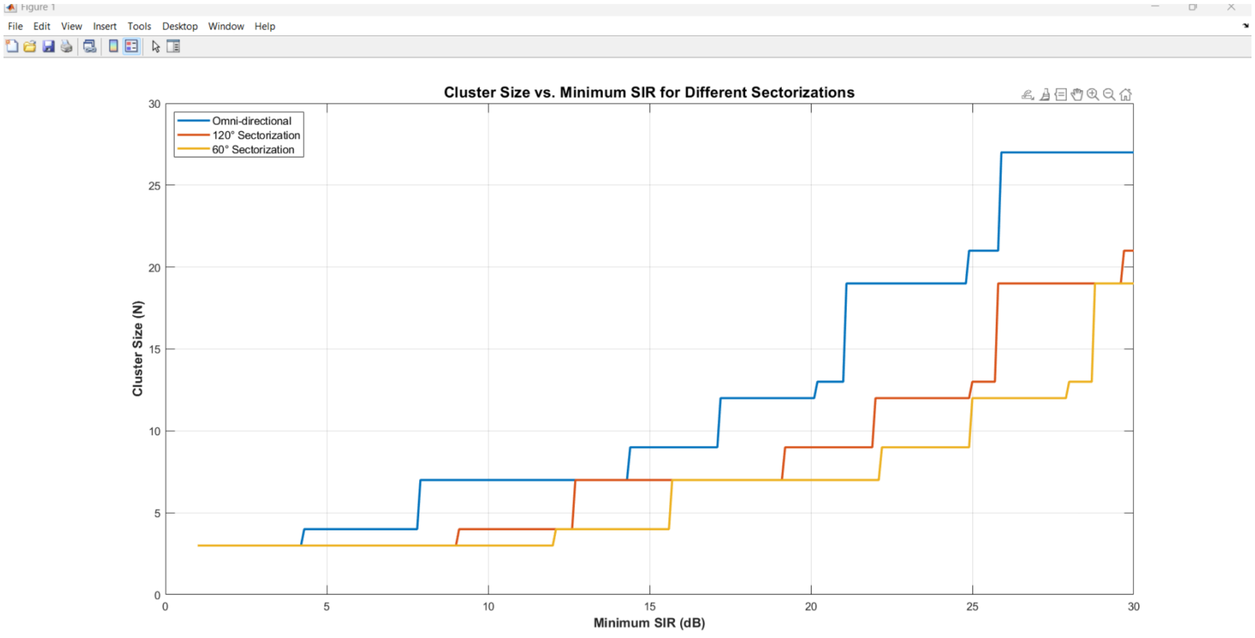
Used to calculate **path loss** based on:

- Frequency: **900 MHz**
- BS Height: **20 m**
- MS Height: **1.5 m**
- Environment: **Urban (medium-sized city)**
- Path Loss Exponent: **4**

Note: Click **"here"** to get the code!

Part B:

1. plot for the cluster size versus SIR_{min}:



Explanation:

To achieve a higher Signal-to-Interference Ratio (SIR), a **larger cluster size is typically required** to **minimize co-channel interference**.
However, sectorization improves interference management, allowing the system to meet the desired SIR with a smaller cluster size.

Code Explanation for Part B (1):

Main Function: `wireless_network_analysis()`

This function sets up the environment by defining key parameters:

- `city_area = 100 km²`: Size of the urban area under consideration.
- `total_channels = 340`: Number of available channels.
- `traffic_per_user = 0.025 Erlang`: Traffic demand per user.
- `h_b = 20`: Base station antenna height in meters.
- `h_m = 1.5`: Mobile station antenna height in meters.
- `n = 4`: Path loss exponent, typical for urban environments.

Then it calls the function `plot_cluster_size_vs_sir()` to perform the analysis.

Function: `plot_cluster_size_vs_sir()`

This function calculates and plots the required cluster size (N) versus the minimum required SIR for the three sectorization cases.

Key Parameters:

- `SIR_range = 1:0.1:30`: Simulated SIR values ranging from 1 dB to 30 dB in 0.1 dB steps.
- `possible_N = [1, 3, 4, 7, 9, 12, 13, 19, 21, 27]`: Valid cluster sizes based on hexagonal geometry (`N = i² + ij + j²`).

Sectorization Impact:

- **Omnidirectional**: No adjustment to SIR.
- **120° sectorization**: SIR improves by approximately 4.77 dB.
- **60° sectorization**: SIR improves by approximately 7.78 dB.

These improvements are accounted for by subtracting the respective dB values from the required SIR before computing the minimum cluster size.

Plot:

The function then generates a plot showing:

- X-axis: Required minimum SIR in dB
- Y-axis: Cluster size (N)
- Three curves representing each sectorization case
- A legend, grid, and labels for clarity

Function: `find_min_cluster_size(SIR_dB, n, possible_N)`

This function determines the smallest cluster size `N` that satisfies a given minimum required SIR using the following model:

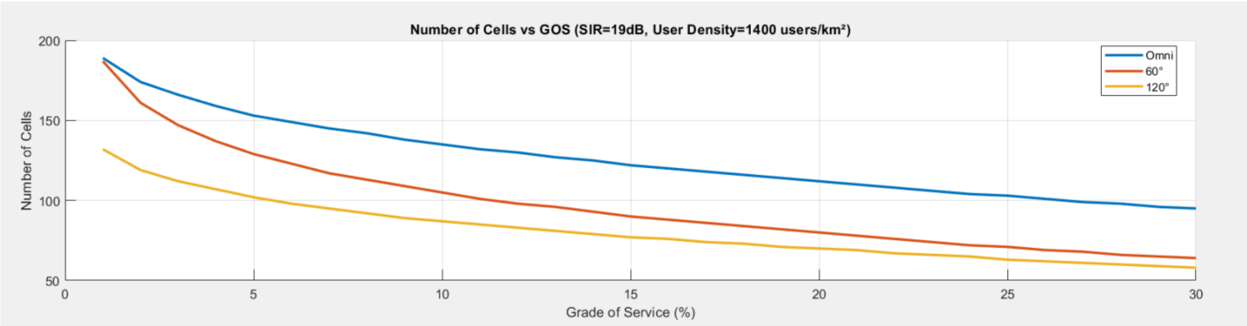
$$\mathrm{SIR}_{\mathrm{dB}} = 10 \cdot \log_{10}\left(\frac{(q-1)^n}{6}\right), \quad \text{where } q = \sqrt{3N}$$

It iterates over each cluster size in `possible_N` and returns the first `N` that satisfies `SIR_actual >= SIR_dB`. If no value meets the condition, it returns the largest value in `possible_N`.

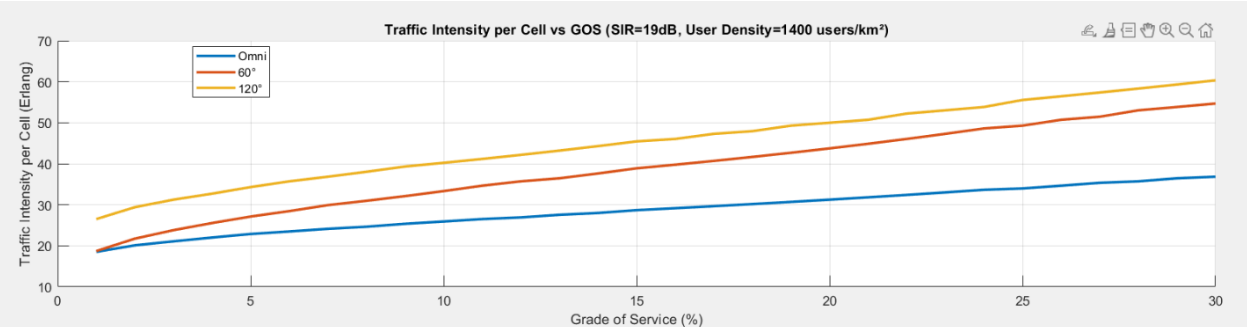
Note: Click "**here**" to get the code!

2. At $SIRmin$ =19dB and user density = 1400 users/km2:

I. A plot for the number of cells versus GOS



II. A plot for the traffic intensity per cell versus GOS



Explanation:

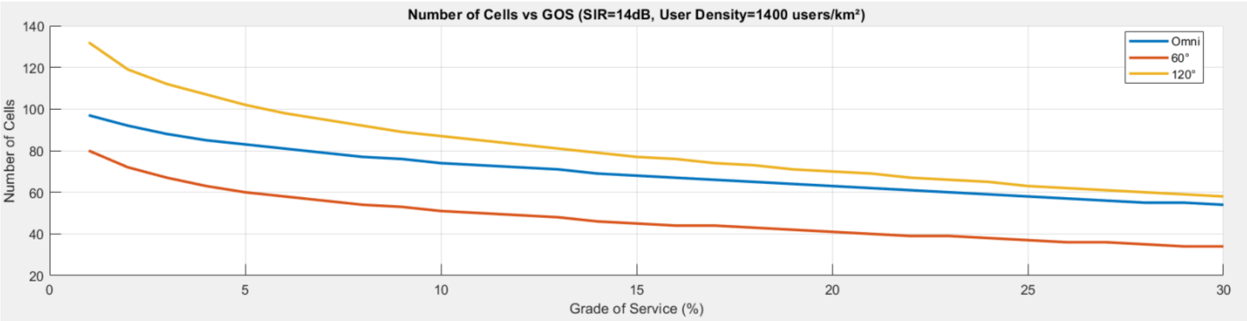
In **First Figure**, it is evident that a higher number of cells is required to achieve better Grade of Service (GOS). However, using sectorization helps reduce the number of required cells by enabling each cell to handle more traffic.

To ensure improved GOS, the system assigns lower traffic per cell, resulting in more reliable service as shown in **Second Figure**.

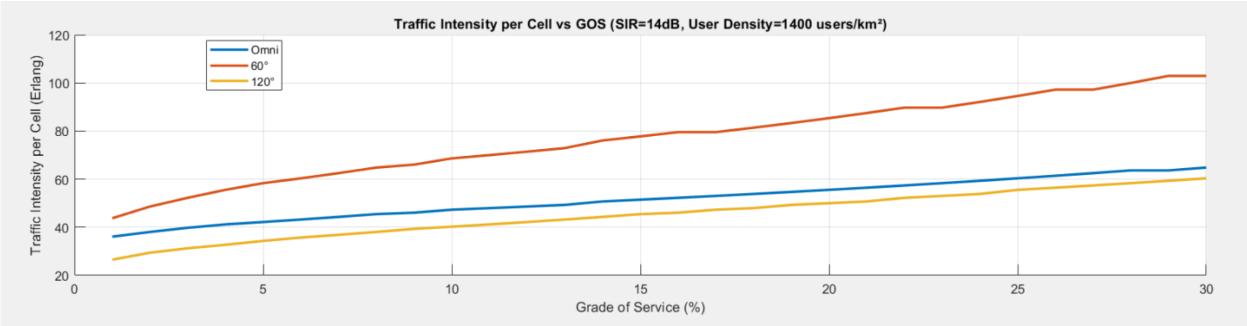
Moreover, sectorization allows a higher traffic load per cell compared to the omnidirectional configuration, due to the increased number of channels assigned per cell, which is also depicted in **Second Figure**.

3. At $SIRmin$ =14dB & user density = 1400 users/km2:

I. A plot for the number of cells versus GOS



II. A plot for the traffic intensity per cell versus GOS



Explanation:

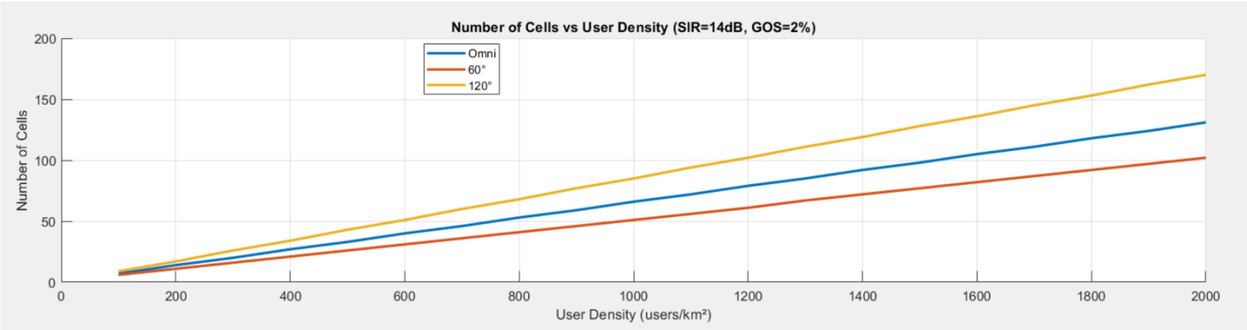
From **First Figure**, we observe that achieving a better Grade of Service (GOS) requires an increase in the number of cells. However, sectorization helps reduce the total number of required cells by allowing each cell to handle more traffic, depending on the cluster size.

To improve GOS, the traffic per cell must be reduced, resulting in more reliable service, as shown in **Second Figure**.

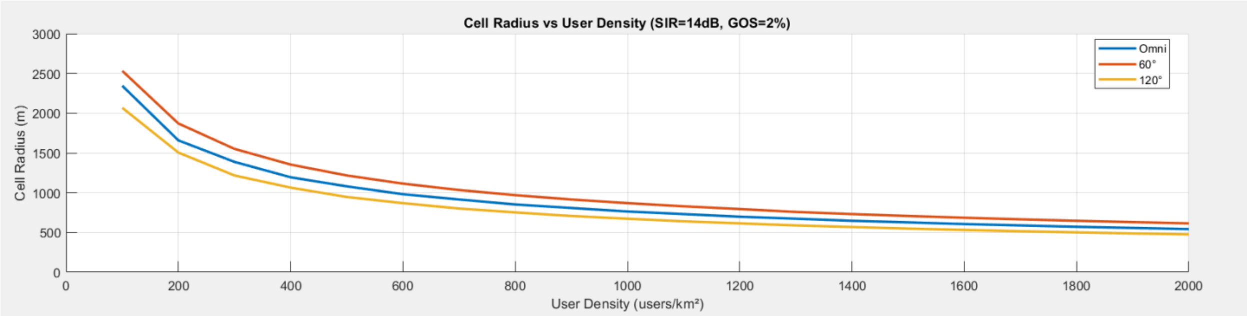
Additionally, sectorization enables each cell to manage more traffic than in the omnidirectional case, as it provides more channels per cell, which is also demonstrated in **Second Figure**.

4. At SIRmin = 14dB & GOS = 2%:

I. A plot for the number of cells versus Density



II. A plot for the cell radius versus User Density

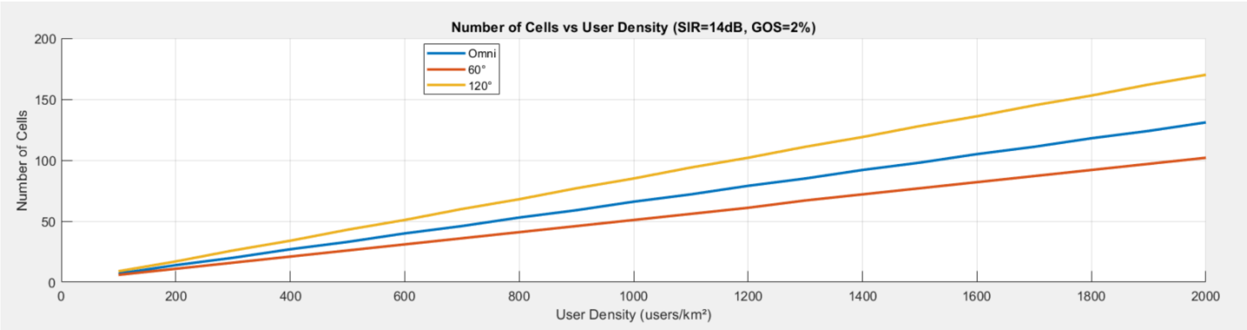


Explanation:

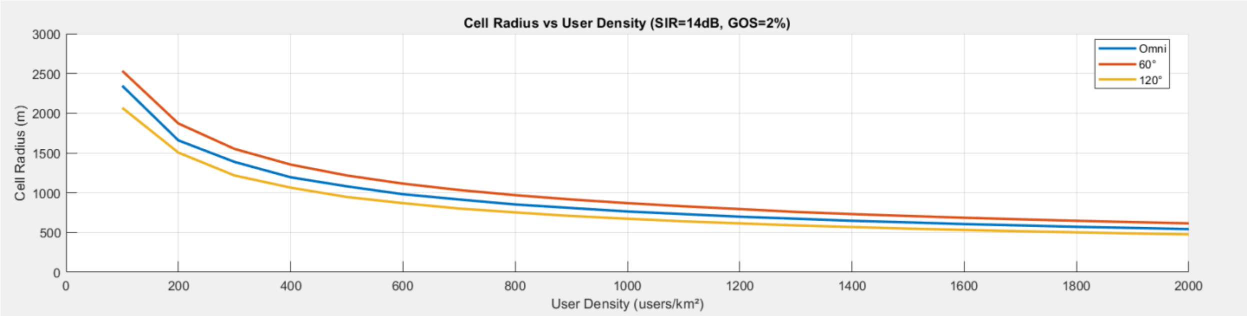
As illustrated in **First Figure**, the number of required cells increases with higher user density, since more users need to be accommodated.
Sectorization, however, allows fewer cells to serve the same number of users by enabling each cell to carry a greater traffic load, depending on the cluster size.
The stepwise nature observed in all the figures results from the small increment used when varying the user density.
In **Second Figure**, it is evident that as the number of users grows, the radius of each cell decreases. This is because the total area remains constant; thus, to accommodate more cells within the same coverage area, each cell must be smaller in size.

5. At SIRmin = 19dB & GOS = 2%:

I. A plot for the number of cells versus Density



II. A plot for the cell radius versus User Density



Explanation:

As illustrated in **First Figure**, the number of required cells increases as user density rises, in order to accommodate the growing total number of users.

Sectorization helps reduce the number of required cells by enabling each cell to handle more traffic, which is influenced by the cluster size.

The step-like behavior observed in the figures is due to the fact that the number of cells can only take integer values.

As shown in **Second Figure**, the radius of each cell decreases with an increase in the number of users. Since the total coverage area remains constant, a higher number of cells within that area results in a noticeable reduction in cell radius.

Code Explanation for Part B (2 to 5):

Main Structure

1. Main Function: wireless_network_planner

- Sets up system constants and input parameters.
- Calls the `generate_plots` function to create all visualizations.

2. Plot Generation: generate_plots

- Creates comparative plots for different planning scenarios.
- Simultaneously tests **three sectorization types**:
  - Omnidirectional (omni)
  - 60° sectorization (6 sectors)
  - 120° sectorization (3 sectors)
- Produces **four sets of plots** for varying network parameters.

3. Core Calculations: calculate_network_params

- Performs core computations for all network parameters.
- Called repeatedly for different configurations to generate data for plots.

4. Cluster Size Calculation: calculate_cluster_size

- Determines the **minimum cluster size (N)** that meets SIR requirements.
- Sectorization-specific interference calculations:
  - **Omni:** 6 interfering cells
  - **120°:** 2 interfering cells per sector
  - **60°:** 1 interfering cell per sector

Key Features

1. Comparative Analysis

- Analyzes and compares:
  - **Omnidirectional**
  - **3-sector (120°)**
  - **6-sector (60°)** sectorization types

Scenario	Fixed Parameters	Varied Parameter	Insights
1. Number of Cells vs GOS (SIR = 19 dB)	SIR = 19 dBUser Density = 1400 users/km²	GOS	Impact of GOS on required cells and traffic per cell
2. Number of Cells vs GOS (SIR = 14 dB)	SIR = 14 dBUser Density = 1400 users/km²	GOS	Effect of relaxed SIR on network capacity
3. Cell Count & Radius vs User Density (SIR = 14 dB, GOS = 2%)	SIR = 14 dBGOS = 2%	User Density	How cell count and size scale with user growth
4. Cell Count & Radius vs User Density (SIR = 19 dB, GOS = 2%)	SIR = 19 dBGOS = 2%	User Density	Stricter SIR's effect on infrastructure

Technical Implementation

Cluster Size Calculation

- Computes **minimum N** using standard cellular interference models.
- Adjusts based on sectorization type.

Traffic Capacity

- Uses **Erlang B Table** for calculating blocking probability.
- Implements **linear interpolation** for GOS values between table entries.
- Applies **approximation formula** for values outside the table range.

Cell Planning Logic

- Calculates number of cells using:
  - User density
  - Traffic per user (0.025 Erlang)
  - Max supported traffic per cell/sector
- Computes cell radius using **hexagonal cell area** formula.

Visualization Strategy

- Uses MATLAB's `subplot` for related visual comparisons.
- Maintains:
  - Consistent **colors** and **line styles**
  - Clear **titles**, **axes labels**, **legends**
  - **Grid lines** for better readability

How to Interpret the Output

GOS Analysis Plots

- Top Plot: Number of Cells vs GOS
- Bottom Plot: Traffic per Cell vs GOS
- Insight: Understand trade-off between service quality (GOS) and infrastructure size.

User Density Analysis Plots

- Top Plot: Number of Cells vs User Density
- Bottom Plot: Cell Radius vs User Density
- Insight: Understand how the network must scale with increasing user demand.

For Each Plot:

- Compare **sectorization strategies** directly.
- Observe the effect of **SIR (14 dB vs 19 dB)**.
- Study how **GOS** and **user density** impact **infrastructure** needs.

Note: Click **"here"** to get the code!