Pabna University Of Science And Technology

Lab Report

Faculty of Engineering and Technology

Department Of Information And Communication Engineering

Course Title: Cellular and Mobile Communication Sessional

Course Code : ICE-4104

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1. If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses

(a) 4-cell reuse,
(b) 7-cell reuse
(c) 12-cell reuse.

If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

2. If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) $n = 4$, (b) $n = 3$?

Assume that there are 6 co-channels cells in the first tier and all of them are at the same distance from the mobile. Use suitable approximations.

3. How many users can be supported for 0.5% blocking probability for the following number of trunked channels in a blocked calls cleared system?

a. **1,**
b. **5,**
c. **10,**
d. **20,**
e. **100**.

Assume each user generates 0.1 Erlangs of traffic.

4. An urban area has a population of 2 million residents. Three competing trunked mobile networks (systems A, B, and C) provide cellular service in this area. System A has 394 cells with 19 channels each, system B has 98 cells with 57 channels each, and system C has 49 cells, each with 100 channels. Find the number of users that can be supported at 2% blocking if each user averages 2 calls per hour at an average call duration of 3 minutes. Assuming that all three trunked systems are operated at maximum capacity, compute the percentage market penetration of each cellular provider.

5. A certain city has an area of 1,300 square miles and is covered by a cellular system using a 7-cell reuse pattern. Each cell has a radius of 4 miles and the city is allocated 40 MHz of spectrum with a full duplex channel bandwidth of 60 kHz. Assume a GOS of 2% for an Erlang B system is specified. If the offered traffic per user is 0.03 Erlangs, compute

a. **the number of cells in the service area,**
b. **the number of channels per cell,**
c. **traffic intensity of each cell,**

d. **the maximum carried traffic;**
e. **the total number of users that can be served for 2% GOS,**
f. **(f') the number of mobiles per channel, and**
g. **the theoretical maximum number of users that could be served at one time by the system.**

6. If a transmitter produces 50 watts of power, it expresses the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna, what is P (10 km)? Assume unity gain for the receiver antenna.

7. Determine the path loss of a 900MHz cellular system in a large city from a base station with the height of 100m and mobile station installed in a vehicle with antenna height of 2m. The distance between mobile and base station is 4Km.

8. Determine the path loss between base station (BS) and mobile station (MS) of a 1.8GHz PCS system operating in a high-rise urban area. The MS is located in a perpendicular street to the location of the BS. The distances of the BS and MS to the corner of the street are 20 and 30 meters, respectively. The base station height is 20m.

9. A mobile is located 5 km away from a base station and uses a vertical λ /4 monopole antenna with a gain of 2.55 dB to receive cellular 3 radio signals. The E-field at 1 km from the transmitter is measured to be V/rn. The carrier frequency used for this system is 900 MHz.

a. **Find the length and the gain of the receiving antenna.**
b. **Find the received power at the mobile using the 2-ray ground reflection model**

assuming the height of the transmitting antenna is 50 m and the receiving antenna is 1.5m above ground.

10. A hexagonal cell within a 4-cell system has a radius of 1.387 km. A total of 60 channels are used within the entire system. If the load per user is 0.029 Erlangs, and λ= call/hour, compute the following for an Erlang C system that has a 5% probability of a delayed call:

a. **How many users per square kilometer will this system support?**
b. **What is the probability that a delayed call will have to wait for more than 10s?**
c. **What is the probability that a call will be delayed for more than 10 seconds?**

Experiment No: 01

Experiment Name: If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses

(a) 4-cell reuse,
(b) 7-cell reuse,
(c) 12-cell reuse.

If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

Objectives:

i) Calculate the number of available channels per cell in an FDD cellular system using different cell reuse factors (4, 7, and 12).
ii) Determine an equitable distribution of control and voice channels in each cell considering dedicated spectrum for control channels.

Theory:

Frequency-Division Duplex (FDD) is a cellular network access method where separate frequency bands are used for uplink and downlink transmissions. This allows simultaneous communication between user and base station without interference. Each frequency band is further divided into channels, which are allocated to different users for voice or data communication.

The number of available channels per cell depends on several factors, including:

- Total system bandwidth
- Channel spacing (bandwidth of each individual channel)
- Frequency reuse factor (number of cells using the same frequency band)

A higher reuse factor implies fewer channels per cell but increases spatial reuse, leading to better overall system capacity.

Solution:

Given:

Total bandwidth =33MHZ

Channel bandwidth=25*2=50kHz/duplex channel

Total available channels=33000/50

=660 channels

a) For N=4,

Total number of channels available per cell=660/4 =165 channels

b) For N=7,

Total number of channels available per cell=660/7=94 channels

c) For N=12,

Total number of channels available per cell=660/12=55channels

The number of available control channel=1000/50

=20

If 1MHz Spectrum for control channels implies that there are 1000/50=20 control channels out of the 660 channels available.

Now,

- **a)** For N=4, we can have (660-20)/4=160 voice channels and 20/4=5 control channel/cell
- **b)** For N=7, we can have (660-20)/7=91 voice channels and 20/7=3 control channel/cell
- **c)** For N=12, we can have (660-20)/12=53 voice channels and 20/12=2 control channel/cell

Python Source Code:

```
bw = 33e3

single_channel_bw = 25

# duplex channel bandwidth

duplex_channel_bw = 2 * single_channel_bw

print('Channel bw =', duplex_channel_bw)

# total channel

total_channel = bw // duplex_channel_bw

print('Total available channel =', total_channel)

# control channel bandwidth

controlChannel_bw = 1000

# total control channel

total_controlChannel = controlChannel_bw // duplex_channel_bw

print('Total Control Channel =', total_controlChannel)

# Array of different value for N(number of cells)

print('----------------------------------------------')

print('For various cluster size')

print('----------------------------------------------')
```

```
N = [4, 7, 12]
for cluster_size in N:
    # cluster size
    print('Cluster Size=', cluster_size)
    # channel per cells
    channel_per_cell = total_channel // cluster_size
    print('Channel per cell =', channel_per_cell)
    # control channels per cell
    controlChannel_per_cell = total_controlChannel // cluster_size
    print('Control channel =', controlChannel_per_cell)
    # voice channel per cell
    voiceChannel = (total_channel - total_controlChannel) // cluster_size
    print('Voice channel =', voiceChannel)
    print('-----------------------------------------------')
```

Output:

```
Channel bw = 50
Total available channel = 660.0
Total Control Channel = 20
-----------------------------------------------
For various cluster size
-----------------------------------------------
Cluster Size= 4
Channel per cell = 165.0
Control channel = 5
Voice channel = 160.0
-----------------------------------------------
Cluster Size= 7
Channel per cell = 94.0
Control channel = 2
```

Voice channel = 91.0

Cluster Size= 12

Channel per cell = 55.0

Control channel = 1 Voice channel = 53.0

Experiment No: 02

Experiment Name: If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is

a. **n= 4**
b. **n = 3**

Assume that there are 6 co-channels cells in the first tier and all of them are at the same distance from the mobile. Use suitable approximations.

Objectives:

1. To determine the optimal frequency reuse factor and cluster size for a cellular system to maximize capacity while ensuring satisfactory forward channel performance.
2. To investigate the impact of different path loss exponents on the selection of frequency reuse factor and cluster size.
3. To understand the concepts of frequency reuse factor, cluster, cluster size, and co-channels in cellular communication systems.

Theory:

Frequency Reuse Factor:

The frequency reuse factor (N) is a crucial parameter in cellular communication systems that determines the reuse of the same frequency channels across different cells. It represents the ratio of the total number of available channels to the number of channels used within each cell. A lower frequency reuse factor allows for more efficient spectrum utilization but may lead to increased interference. The formula to calculate the frequency reuse factor is given by:

$$N = \frac{1}{1+\frac{1}{SIR}}$$

where SIR is the required Signal-to-Interference Ratio.

Cluster and Cluster Size:

- In cellular networks, cells are grouped into clusters to manage interference and optimize frequency reuse.
- A cluster is a group of cells in which the same set of frequencies can be reused without causing significant interference.
- Cluster size (K) represents the number of cells in a cluster.

Co-Channels:

- Co-channels are channels that use the same frequency but belong to different cells.
- In a cellular system, neighboring cells may share co-channels to optimize spectrum utilization.

- Co-channel interference occurs when signals from co-channel cells interfere with each other, affecting the quality of communication.
- Proper management of co-channels is essential to minimize interference and ensure efficient system performance.

Solution:

a) n=4

first, let us consider a seven-cell reuse pattern using equation $Q = \left(\frac{D}{R}\right) = \sqrt{3N}$, frequency reuse factor, $Q = \left(\frac{D}{R}\right) = \sqrt{3N} = \sqrt{21}$ =4.583

The signal to noise interference ratio is given by $\frac{S}{I} = \left(\frac{1}{6}\right) * (4.583)^4 = 75.5 = 18.66\text{dB}$

Since this is greater than the minimum required

$\frac{S}{I}$, $N = 7$ can be used

b) n=3

First, let us consider a seven-cell reuse pattern. The signal to interference ratio is given by

$$\frac{S}{I} = \left(\frac{1}{6}\right) * (4.583)^3$$
$$= 16.04 = 12.05dB$$

Since this is less than the minimum required $\frac{S}{I}$, the need to use a large N. Using equation $N = i^2 + i.j + j^2$. The next possible value is N is 12 $(i = j = 2)$. The corresponding co-channel ration is given by $\frac{D}{R} = 6.0$

Now, the signal-to-interference ration is given by, $\frac{S}{I} = \left(\frac{1}{6}\right) * (6)^3$

$$= 36 = 15.56\ dB$$

Since this is greater than the minimum required $\frac{S}{I}$, $N = 12$ is used.

Python Source Code:

```
import math
def calculate_frequency_reuse_factor(N):
    Q = math.sqrt(3 * N)
    return Q
```

```
def calculate_SIR(io, n, Q):
    SI = 10 * math.log10((1 / io) * (Q ** n))
    return SI


def find_optimal_parameters(R_SI, io, N):
    for n in [4, 3]:
        Q = calculate_frequency_reuse_factor(N)
        SI = calculate_SIR(io, n, Q)
        print(f"For n = {n}:")
        print(f"Frequency reuse factor (Q): {Q}")
        print(f"Signal to interference ratio (SI): {SI} dB")


        if SI < R_SI:
            # Adjusting parameters
            i = 2
            j = 2
            N = i ** 2 + i * j + j ** 2
            Q = calculate_frequency_reuse_factor(N)
            SI = calculate_SIR(io, n, Q)
            print("Adjusting parameters:")
            print(f"New Frequency reuse factor (Q): {Q}")
            print(f"New Signal to interference ratio (SI): {SI} dB")
        print()
# Given parameters
R_SI = 15  # Required signal to interference ratio (dB)
io = 6  # Path loss exponent
# Finding optimal parameters
find_optimal_parameters(R_SI, io, 7)
```

Output:

For n = 4:

Frequency reuse factor (Q): 4.58257569495584

Signal to interference ratio (SI): 18.66287339084195 dB

For n = 3:

Frequency reuse factor (Q): 4.58257569495584

Signal to interference ratio (SI): 12.051776917172353 dB

Adjusting parameters:

New Frequency reuse factor (Q): 6.0

New Signal to interference ratio (SI): 15.563025007672874 dB

Experiment No: 03

Experiment Name: How many users can be supported for 0.5% blocking probability for the following number of trunked channels in a blocked calls cleared system?

(a) 1,
(b) 5,
(c) 10,
(d) 20,
(e) 100.

Assume each user generates 0.1 Erlangs of traffic.

Objective:

This report investigates the number of users a blocked calls cleared system can support while maintaining a 0.5% blocking probability. We analyze different scenarios with varying numbers of trunked channels, assuming each user generates 0.1 Erlangs of traffic.

Theory:

Offered Load per User: We consider 0.1 Erlangs as the offered load per user based on the provided information.

Blocking Probability: The desired blocking probability (B) is 0.5%, which translates to 0.005.

Erlang C Formula: We employ the Erlang C formula to calculate the offered load (A) that achieves the target blocking probability for each scenario with varying numbers of trunks (N):

$$A = \frac{-N * \ln(B)}{(N-B)}$$

Number of Users Supported: By dividing the total offered load (A) by the offered load per user, we determine the number of users supported (U):

$$U = \frac{A}{L}$$

From the Erlang B chart, we can find the total capacity for the 0.5% GOS for a different number of channels. By using the relation, $A = UAv$, we can obtain the total number of bands that can be supported in the system.

a) Given $e = 1,\ Au = 0.1\ GOS = 0.005$

From Erlang B chart we obtain $A = 0.005$

Therefore, total number of users, $U = \frac{A}{Au}$

$$= \frac{0.005}{0.1} = 0.05 \text{ users}$$

But one user could be supported on one channel, so, $\mu = 1$

b) Given, $e = 5,\ Au = 0.1,\ GOS = 0.005$

From Erlang B chart we obtain $A = 1.13$

Therefore, total number of users, $U = \frac{A}{Au}$

$$= \frac{1.13}{0.1}$$

$$= 11 \text{ users}$$

c) Given, $e = 10,\ Au = 0.1,\ GOS = 0.005$

From Erlang B chart we obtain $A = 3.96$

Therefore, total number of users, $U = \frac{A}{Au}$

$$= \frac{3.96}{0.1}$$

$$= 39 \text{ users}$$

d) Given, $e = 20,\ Au = 0.1,\ GOS = 0.005$

From Erlang B chart we obtain $A = 11.10$

Therefore, total number of users, $U = \frac{A}{Au}$

$$= \frac{11.10}{0.1}$$

$$\sim 110 \text{ users}$$

e) Given, $e = 100,\ Au = 0.1,\ GOS = 0.005$

From Erlang B chart we obtain $A = 80.9$

Therefore, total number of users, $U = \frac{A}{Au}$

$$= \frac{80.9}{0.1}$$

$$= 809 \text{ users}$$

Python Source Code:

```
Gos = 0.5 / 100

Au = 0.1

# from table

A = [0.005, 1.13, 3.96, 11.1, 80.9]

c = [1, 5, 10, 20, 100]
```

```
# c = input("Input a number")

print("Blocking probability")
print(Gos)
print("Traffic intensity per user ")
print(Au)
print("Traffic intensity")
print(A)
print("Channel")
print(c)

# Calculate number of users
U = [a / Au for a in A]
u = [round(u_val) for u_val in U]

# Display number of users
print("Number of users")
print(u)
```

Output:

```
Blocking probability
0.005
Traffic intensity per user
0.1
Traffic intensity
[0.005, 1.13, 3.96, 11.1, 80.9]
Channel
[1, 5, 10, 20, 100]
Number of users
[0, 11, 40, 111, 809]
```

Experiment No: 04

Experiment Name: An urban area has a population of 2 million residents. Three competing trunked mobile networks (systems A, B, and C) provide cellular service in this area. System A has 394 cells with 19 channels each, system B has 98 cells with 57 channels each, and system C has 49 cells, each with 100 channels. Find the number of users that can be supported at 2% blocking if each user averages 2 calls per hour at an average call duration of 3 minutes. Assuming that all three trunked systems are operated at maximum capacity, compute the percentage market penetration of each cellular provider.

Objectives:

This analyzes the capacity of three competing cellular networks (A, B, and C) in an urban area with 2 million residents. It aims to determine the number of users each network can support at a 2% blocking probability, assuming specific user activity parameters and maximum network capacity. The report also calculates the market penetration percentage for each network.

Theory:

- **Trunked Mobile Network:** An analog cellular network where channels are shared among users by a central controller, allowing more users than available channels.
- **Blocking Probability:** The probability that a call attempt is denied due to a lack of available channels.
- **Erlang B Model:** A mathematical model used to calculate blocking probability in trunked systems based on the number of channels, traffic intensity (calls per hour), and average call duration.
- **Market Penetration:** The percentage of the total population that subscribes to a specific network.

Procedure:

System A

Given:

Probability of blocking = 2% = 0.02

Number of channels per cell used in the system, C = 19

Traffic intensity per user, $Au = \lambda H = 2 \times \left(\frac{3}{60}\right) = 0.1$ Erlangs

For GOS = 0.02 and C = 19, from the Erlang B chart, the total carried

traffic, A, is obtained as 12 Erlangs.

Therefore, the number of users that can be supported per cell is

$U = \frac{A}{Au} = \frac{12}{.1} = 120.$

Since there are 394 cells, the total number of' subscribers that can be sup

ported by System A is equal to $120 \times 394 = 47280.$

System B

Given:

Probability of blocking = 2% = 0.02

Number of channels per cell used in the system, C = 57

Traffic intensity per user, $Au = \lambda H = 2 \times \left(\frac{3}{60}\right) = 0.1$ Erlangs

For GOS = 0.02 and C = 57, from the Erlang B chart, the total carried

traffic, A, is obtained as 45 Erlangs.

Therefore, the number of users that can be supported per cell is

$U = \frac{A}{Au} = \frac{45}{0.1} = 450.$

Since there are 98 cells, the total number of subscribers that can be supported by System B is equal to $450 \times 98 = 441$ W.

System C

Given:

Probability of blocking 2%

= 0.02

Number of channels per cell used in the system, C = 100

Traffic intensity per user,

$Au = \lambda H = 2 \times \left(\frac{3}{60}\right) = 0.1$ Erlangs

For GOS = 0.02 and C = 100, from the Erlang B chart, the total carried

traffic, A, is obtained as 88 Erlangs.

Therefore, the number of users that can be supported per cell is

$U = \frac{A}{Au} = \frac{88}{0.1} = 880.$

Since there are 49 cells, the total number of subscribers that can be supported by System C is equal to $880 \times 49 = 43120$

Therefore, the total number of cellular subscribers that can be supported by these three systems are $47280 + 44100 + 43120 = 134500$ users.

Since there are 2 million residents in the given urban area and the total number of cellular subscribers in System A is equal to 47280, the percentage market penetration

is equal to $\frac{47280}{2000000} = 2.36\%$

Similarly, market penetration of System B is equal to

$$\frac{44100}{2000000} = 2.205\%$$

and the market penetration of System C is equal to

$$\frac{43120}{2000000} = 2.156\%$$

The market penetration of the three systems combined is equal to

$$\frac{134500}{2000000} = 6.725\%$$

Python Source Code:

```
blocking_p = 2 / 100

lamda = 2

H = 3 / 60

Au = lamda * H


# System A

channel_a = 19

cell_A = 394

A = 12

Ua = A / Au

subscriber_A = Ua * cell_A

percentage_market_penetration_for_A = (subscriber_A / 2000000) * 100


# System B

channel_b = 57

cell_B = 98

Ab = 45

Ub = Ab / Au

subscriber_B = Ub * cell_B

percentage_market_penetration_for_B = (subscriber_B / 2000000) * 100
```

```
# System C
channel_c = 100
cell_C = 49
Ac = 88
Uc = Ac / Au
subscriber_C = Uc * cell_C
percentage_market_penetration_for_C = (subscriber_C / 2000000) * 100

Total_number_of_subscriber = subscriber_A + subscriber_B + subscriber_C
Market_penetration_for_three_system = (Total_number_of_subscriber / 2000000) * 100
print("For system A:")
print("Number of users in System A:", Ua)
print("Total number of subscriber in system A:", subscriber_A)
print("Percentage market penetration for A:", percentage_market_penetration_for_A)

print("\nFor system B:")
print("Number of users in System B:", Ub)
print("Total number of subscriber in system B:", subscriber_B)
print("Percentage market penetration for B:", percentage_market_penetration_for_B)

print("\nFor system C:")
print("Number of users in System C:", Uc)
print("Total number of subscriber in system C:", subscriber_C)
print("Percentage market penetration for C:", percentage_market_penetration_for_C)

print("\nTotal number of subscribers for all three systems:", Total_number_of_subscriber)
print("Market penetration for all three systems:", Market_penetration_for_three_system)
```

Output:

For system A:

Number of users in System A: 120.0

Total number of subscribers in system A: 47280.0

Percentage market penetration for A: 2.3640000000000003

For system B:

Number of users in System B: 450.0

Total number of subscribers in system B: 44100.0

Percentage market penetration for B: 2.205

For system C:

Number of users in System C: 880.0

Total number of subscribers in system C: 43120.0

Percentage market penetration for C: 2.156

Total number of subscribers for all three systems: 134500.0

Market penetration for all three systems: 6.7250000000000005

Experiment No: 05

Experiment Name: A certain city has an area of 1,300 square miles and is covered by a cellular system using a 7-cell reuse pattern. Each cell has a radius of 4 miles and the city is allocated 40 MHz of spectrum with a full duplex channel bandwidth of 60 kHz. Assume a GOS of 2% for an Erlang B system is specified. If the offered traffic per user is 0.03 Erlangs, compute

- **a) The number of cells in the service area**
- **b) The number of channels per cell**
- **c) Traffic intensity of each cell**
- **d) The maximum carried traffic**
- **e) The total number of users that can be served for 2% GOS, (f') the number of mobiles per channel**
- **f) The theoretical maximum number of users that could be served at one time by the system.**

Objectives:

This report analyzes the capacity of a cellular system covering a city of 1,300 square miles with a 7-cell reuse pattern. It aims to determine:

- i) The number of cells in the service area.
- ii) The number of channels per cell.
- iii) Traffic intensity per cell.
- iv) Maximum carried traffic and total users at 2% GOS.
- v) Theoretical maximum number of users.

Theory:

7-cell reuse pattern: Each set of 7 cells uses the same frequency band, minimizing interference.

Erlang B system: A model for analyzing traffic load and blocking probability in trunked systems.

Grade of Service (GOS): Acceptable call blocking probability (2% in this case).

Offered traffic: Average traffic generated per user per unit time (Erlangs).

Carried traffic: Actual traffic handled by the system, considering blocking probability.

Procedure:

- i) Calculate total cell area
- ii) Calculate available channels
- iii) Calculate channels per cell
- iv) Calculate traffic intensity per cell
- v) Calculate maximum carried traffic
- vi) Calculate total users for 2% GOS
- vii) Calculate mobiles per channel

Solution:

(a) Given:

Total coverage area = 1300 miles

Cell radius = 4 miles

The area of a cell (hexagon) can be shown to be 2.5981R2, thus each cell covers

$$2.5981 \times 4^2 = 41.57 \text{ sq mi.}$$

Hence, the total number of cells are $Nc = \frac{1300}{41.57} = 31\ cells$.

(b) The total number of channels per cell (C)

= allocated spectrum I(channel width $\times$ frequency reuse factor)

= 40, 000,000 / (60,000 × 7) = 95 channels/cell

(c) Given:

C = 95, and GOS = 0.02

From the Erlang B chart, we have

traffic intensity per cell A = 84 Erlangs/cell

(d)

Maximum carried traffic = number of cells x traffic intensity per cell

= 31 x 84 = 2604 Erlangs.

(e) Given

Traffic per user = 0.03 Erlangs

Total number of users = Total traffic / traffic per user

= 2604 / 0.02 = 86,800 users.

(f)

Number of mobiles per channel = number of users/number of channels

= 86,800 / 666 = 130 mobiles/channel.

(g) The theoretical maximum number of served mobiles is the number of available channels in the system (all channels occupied) = C × Nc = 95 × 31 = 2945 users, which is 3.4% of the customer base.

Python Source Code:

```
import math
# Given values
area = 1300
radius = 4
each_cell_covers = math.floor(2.5981 * radius ** 2)  # in square kilometers
print('(a)')
number_of_cells = math.floor(area / each_cell_covers)
print("Number of cells:", number_of_cells)

# (b)
allocated_spectrum = 40000
channel_width = 60
frequency_reuse_factor = 7
print('(b)')
number_of_channel_per_cell = math.floor(allocated_spectrum / (channel_width *
frequency_reuse_factor))
print("Number of channels per cell:", number_of_channel_per_cell)

# (c)
print('(c)')
traffic_intensity_per_cell = 84  # from erlang chart B
print("Traffic intensity per cell:", traffic_intensity_per_cell)

# (d)
print('(d)')
maximum_carried_traffic = number_of_cells * traffic_intensity_per_cell
print("Maximum carried traffic:", maximum_carried_traffic)

# (e)
traffic_per_user = 0.03
```

```
print('(e)')
total_number_of_user = maximum_carried_traffic / traffic_per_user
print("Total number of users:", total_number_of_user)

# (f)
number_of_channels = number_of_channel_per_cell * frequency_reuse_factor
print('(f)')
number_of_mobile_per_channel = math.floor(total_number_of_user / number_of_channels)
print("Number of mobiles per channel:", number_of_mobile_per_channel)

# (g)
print('(g)')
theoretical_maximum_number_of_user_that_could_be_served = number_of_cells *
number_of_channel_per_cell
print("Theoretical maximum number of users that could be served:",
    theoretical_maximum_number_of_user_that_could_be_served)
```

Output:

```
(a)
Number of cells: 31
(b)
Number of channels per cell: 95
(c)
Traffic intensity per cell: 84
(d)
Maximum carried traffic: 2604
(e)
Total number of users: 86800.0
(f)
Number of mobiles per channel: 130
(g)
Theoretical maximum number of users that could be served: 2945
```

Experiment No: 06

Experiment Name: If a transmitter produces 50 watts of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna, what is P (10 km)? Assume unity gain for the receiver antenna.

Objectives:

i) Convert the transmit power of 50 watts to units of dBm and dBW.
ii) Calculate the received power in dBm at a free space distance of 100 meters and 10 kilometers from the transmitter, assuming a unity gain antenna and carrier frequency of 900 MHz.

Theory:

dBm (decibel-milliwatts): A logarithmic unit used to express power relative to 1 milliwatt (mW).

dBW (decibel-watts): Similar to dBm, but referenced to 1 watt (W).

Free space path loss: The attenuation of signal strength as it propagates through free space, inversely proportional to the square of the distance**.**

Friis transmission equation: A formula to calculate the received power based on transmit power, antenna gains, frequency, and distance.

Procedure:

I. Transmit Power Conversion
II. Received Power Calculation
    a. Friis transmission equation
    b. Wavelength
    c. Received power at 100 m
    d. Received power at 10 km

Solution:

Transmitter Power, $P_t = 50\ W$

Carrier Frequency, $f_c = 900\ MHz$

(a) Transmitter power, $P_t(dBm) = 10\log[\mathrm{P}_t(mW)/(1mW)]$

$= 47.0\ dBm$

(b) Transmitter power,

$$P_t(dBm) = 10\log[P_t\,(W)/(1W)]$$
$$= 10\log[50] = 17dBm$$

The received power can be determined by using this equation,

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2 (100)^2 (1)} = 3.5 \times 10^{-6}\ \text{W} = 3.5 \times 10^{-3}\ \text{mW}$$

$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5 \times 10^{-3}\ \text{mW}\right) = -24.5\ \text{dBm}.$$

The received power at 10km can be expressed in terms of dBm, where $d_0 = 100m\ and\ d = 10km$

$$P_r(10\ \text{km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right] = -24.5\ \text{dBm} - 40\ \text{dB}$$
$$= -64.5\ \text{dBm}.$$

Python Source Code:

```
# given
import math

Pt = 50  # Transmitter Power
fc = 900  # Carrier Frequency

# a
PtdBm = 10 * math.log10(Pt * 1e3)
print('Transmitted Power: %.1f dBm' % PtdBm)

# b
PtBW = 10 * math.log10(Pt)
print('Transmitted Power: %.1f dBW' % PtBW)

# received power
Gt, Gr, lam, d, L = 1, 1, (1 / 3), 100, 1
Pr = (Pt * Gt * Gr * (lam ** 2)) / (((4 * math.pi) ** 2) * (d ** 2) * L)
PrdBm = 10 * math.log10(Pr * 1e3)
print('Received Power: %.1f dBm' % PrdBm)
```

```
# Pr(10Km)
Pr10Km = PrdBm + 20 * math.log10(100 / 10000)
print('Received Power: %.1f dBm' % Pr10Km)
```

Output:

```
Transmitted Power: 47.0 dBm
Transmitted Power: 17.0 dBW
Received Power: -24.5 dBm
Received Power: -64.5 dBm
```

Experiment No: 07

Experiment Name: Determine the path loss of a 900MHz cellular system in a large city from a base station with the height of 100m and mobile station installed in a vehicle with antenna height of 2m. The distance between mobile and base station is 4Km.

Solution:

We calculate the terms in the Okumura-Hata model as

a(hm)=3.2[log(11.75hm)]^2-4.49

=1.045dB

Lp=69.55+26.16logfe-13.82loghb-a(hm)+[44.9-6.55loghb]logd

=137.3dB

Python Source Code:

```
import math

# Given values
hre = 2  # Height of the receiving antenna (meters)
hte = 100  # Height of the transmitting antenna (meters)
fc = 900  # Frequency (MHz)
d = 4  # Distance between antennas (kilometers)

# Calculate a_hre
a_hre = 3.2 * (math.log10(11.75 * hre)) ** 2 - 4.97

# Calculate path loss
Lp = 69.55 + 26.16 * math.log10(fc) - 13.82 * math.log10(hte) - a_hre + (44.9 - 6.55 * math.log10(hte)) * math.log10(d)

print('Path loss: %.2f' % Lp)
```

Output:

Path loss: 137.29

Experiment No: 08

Experiment Name: Determine the path loss between base station (BS) and mobile station (MS) of a 1.8GHz PCS system operating in a high-rise urban area. The MS is located in a perpendicular street to the location of the BS. The distances of the BS and MS to the corner of the street are 20 and 30 meters, respectively. The base station height is 20m.

Solution:

The distance of the mobile from the base station if sqrt((20)^2+(30)^2) =36.05.

Using the appropriate equation, we can write the path loss as:

Lp=135.41+12.49logfc-4.99logbh+[46.84-2.34loghb]logd

68.89 dB

Python Source Code:

```
import math

# Given values
fc = 1.8  # Frequency (GHz)
hb = 20  # Height of the base station antenna (meters)
d = math.sqrt(20 ** 2 + 30 ** 2) / 1000  # Distance between the base station and mobile station (kilometers)

print('Distance: %.4f Km' % d)

# Calculate path loss
PathLoss = 135.41 + (12.49 * math.log10(fc)) - (4.99 * math.log10(hb)) + ((46.82 - 2.34 * math.log10(hb)) * math.log10(d))

print('PathLoss: %.4f dB' % PathLoss)
```

Output:

Distance: 0.0361 Km

Path Loss: 68.9368 dB

Experiment No: 09

Experiment Name: A mobile is located 5 km away from a base station and uses a vertical λ /4 monopole antenna with a gain of 2.55 dB to receive cellular 3 radio signals. The E-field at 1 km from the transmitter is measured to be V/rn. The carrier frequency used for this system is 900 MHz.

a. **Find the length and the gain of the receiving antenna.**
b. **Find the received power at the mobile using the 2-ray ground reflection model**

assuming the height of the transmitting antenna is 50 m and the receiving antenna is 1.5m above ground.

Solution:

Given:

T-R separation distance = 5 km

E-field at a distance of 1 km = 10^{-3} V/m

Frequency of operation, f = 900 MHz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{900\times10^6} = 0.333 \text{ m.}$$

Length of the antenna, $L = \lambda/4 = 0.333/4 = 0.0833 \text{ m} = 8.33 \text{ cm.}$

Gain of the antenna = $10^{(gain/10)}) = 1.8 = 2.55dB$

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(b) Since $d \gg \sqrt{h_t h_r}$, the electric field is given by

$$E_R(d) \approx \frac{2E_0 d_0}{d}\frac{2\pi h_t h_r}{\lambda d} \approx \frac{k}{d^2} \text{ V/m}$$

$$= \frac{2\times10^{-3}\times1\times10^3}{5\times10^3}\left[\frac{2\pi(50)(1.5)}{0.333\left(5\times10^3\right)}\right]$$

$$= 113.1\times10^{-6} \text{ V/m.}$$

The received power can be obtained by,

$$P_r(d) = \frac{\left(113.1\times10^{-6}\right)^2}{377}\left[\frac{1.8\,(0.333)^2}{4\pi}\right]$$

$$P_r(d = 5 \text{ km}) = 5.4\times10^{-13} \text{ W} = -122.68 \text{ dBW or } -92.68 \text{ dBm.}$$

Python Source Code:

```
import math

# Given values
T_R_distance = 5  # Distance between transmitter and receiver in km
E_field = 1e-3  # Electric field in V/m
f = 900  # Frequency in MHz
d0 = 1000  # Distance for electric field measurement in meters
c = 3e8  # Speed of light in m/s

# Converting frequency to Hz
f *= 1e6

# Calculating wavelength
lamda = c / f

# Height of transmitting and receiving antennas
ht = 50  # in meters
hr = 1.5  # in meters

# Distance from transmitter to receiver
d = T_R_distance * 1000  # in meters

# a
length_of_antenna = lamda / 4
gain = 10 ** (2.55 / 10)
gain_rcv = 10 * math.log10(gain)
print('Gain of Receiving Gain: %.2f dB' % gain_rcv)
effective_aperture = (gain * (lamda ** 2)) / (4 * 3.1416)
# print('Effective aperture is', effective_aperture)
```

```
# b
Er_d = (2 * E_field * d0 * 2 * 3.1416 * ht * hr) / (lamda * d ** 2)
print('Electric Field {:e}'.format(Er_d))


pr_d = ((Er_d ** 2) / (120 * 3.1416)) * effective_aperture
received_power_at_5km_distance = 10 * math.log10(pr_d)
print('Received power at distance in dBW', received_power_at_5km_distance)
received_power2 = 10 * math.log10(pr_d * 1000)
print('Received power at distance in dBm', received_power2)
```

Output:

Number of channels per cell: 15

Area Covered per cell is: 5 sq km

(a) Number of users: 62

(b)

Holding time: 104.40 seconds

Probability to wait: 56.29 %

(c) Probability of delay 2.81 %

Experiment No: 10

Experiment Name: A hexagonal cell within a 4-cell system has a radius of 1.387 km. A total of 60 channels are used within the entire system. If the load per user is 0.029 Erlangs, and λ= call/hour, compute the following for an Erlang C system that has a 5% probability of a delayed call:

(a) How many users per square kilometer will this system support?

(b) What is the probability that a delayed call will have to wait for more than 10s?

(c) What is the probability that a call will be delayed for more than 10 seconds?

Solution:

Given,

Cell radius, $R = 1.387$ km

Area covered per cell is $2.598 \times (1.387)^2 = 5$ sq km

Number of cells per cluster = 4

Total number of channels = 60

Therefore, number of channels per cell = 60 / 4 = 15 channels.

(a) From Erlang C chart, for 5% probability of delay with $C = 15$, traffic intensity = 9.0 Erlangs.

Therefore, number of users = total traffic intensity / traffic per user

$= 9.0/0.029 = 310$ users

$= 310$ users$/5$ sq km $= 62$ users/sq km

(b) Given $\lambda = 1$, holding time

$H = A_u/\lambda = 0.029$ hour $= 104.4$ seconds.

The probability that a delayed call will have to wait for more than 10 s is

$Pr[delay > t|delay] = \exp(-(C-A)t/H)$

$= \exp(-(15-9.0)10/104.4) = 56.29$ %

(c) Given $Pr[delay > 0] = 5\% = 0.05$

Probability that a call is delayed more than 10 seconds,

$Pr[delay > 10] = Pr[delay > 0] Pr[delay > t|delay]$

$= 0.05 \times 0.5629 = 2.81$ %

Python Source Code:

```
# Given values
radius = 1.387
cluster = 4
total_channel = 60
channel_per_cell = total_channel / cluster
each_cell_covers = math.ceil(2.5981 * (radius ** 2))
traffic_per_user = 0.029
t = 10
blocking_probability = 5 / 100

# extra
print('Number of channel per cell: %d' % channel_per_cell)
print('Area Covered per cell is: %d sq km' % each_cell_covers)

traffic_intensity = 9
no_of_user = math.floor(traffic_intensity / (traffic_per_user * each_cell_covers))
print(f'(a) Number of users: {no_of_user}')

print('(b)')
lembda = 1  # Au = lembda/H_holding time
holding_time = (traffic_per_user / lembda) * 60 * 60
print('Holding time: %.2f seconds' % holding_time)
probability_to_wait = math.exp(-(channel_per_cell - traffic_intensity) * t / holding_time) * 100
print(f'Probability to wait: %.2f' % probability_to_wait, '%')

probability_of_delay = blocking_probability * probability_to_wait
print(f'(c) Probability of delay %.2f ' % probability_of_delay, '%')
```

Output:

Number of channels per cell: 15

Area Covered per cell is: 5 sq km

(a) Number of users: 62

(b)Holding time: 104.40 seconds

Probability to wait: 56.29 %

(c) Probability of delay 2.81 %