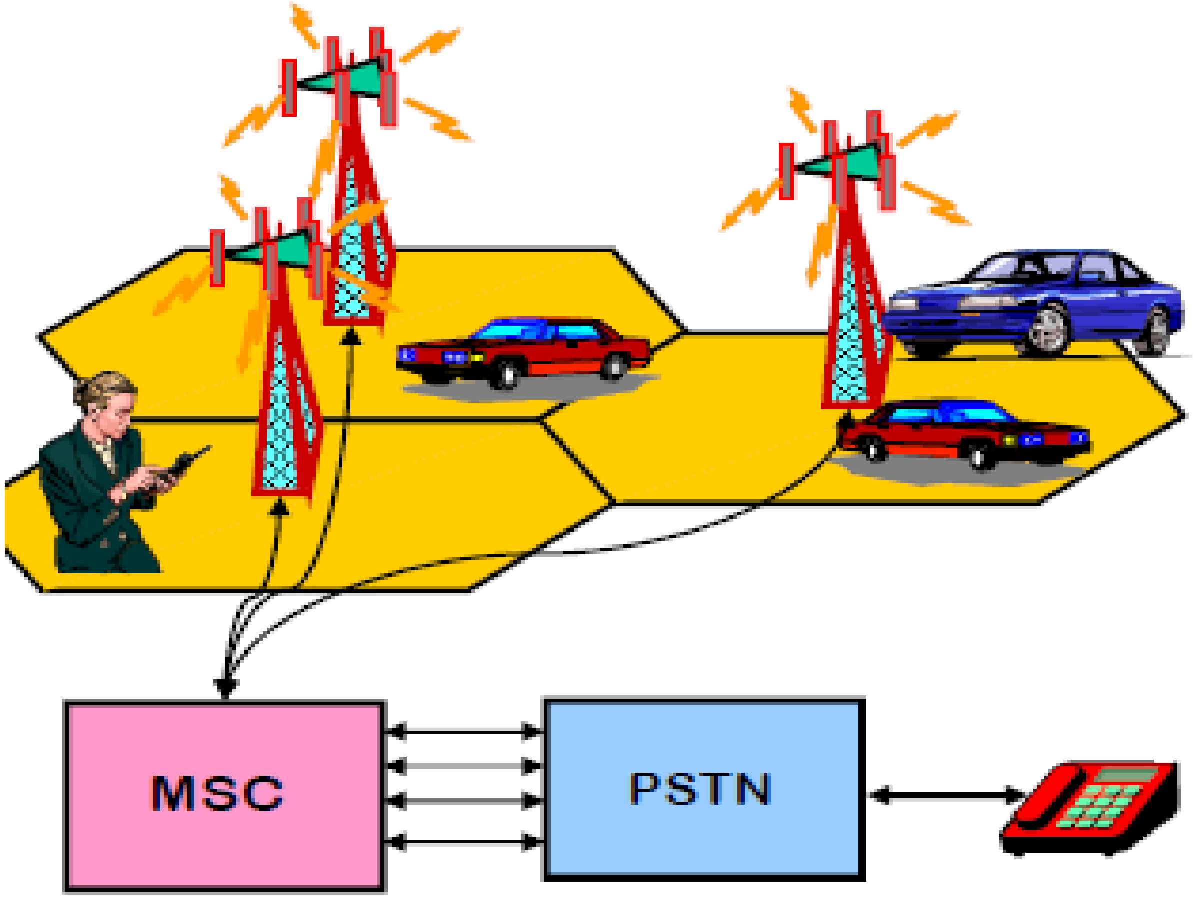
Cellular Concept and Trunking



Cellular Concept

- Simple Solution
  - Single high powered transmitter on a tall tower
  - Good coverage but very low capacity
  - No frequency reuse
- High Capacity Solution
  - Cellular concept solves problem of low capacity
  - Replaces a single high power transmitter (large cell) with many low power transmitters (small cells)
  - Much smaller and more efficient mobile units

Operation

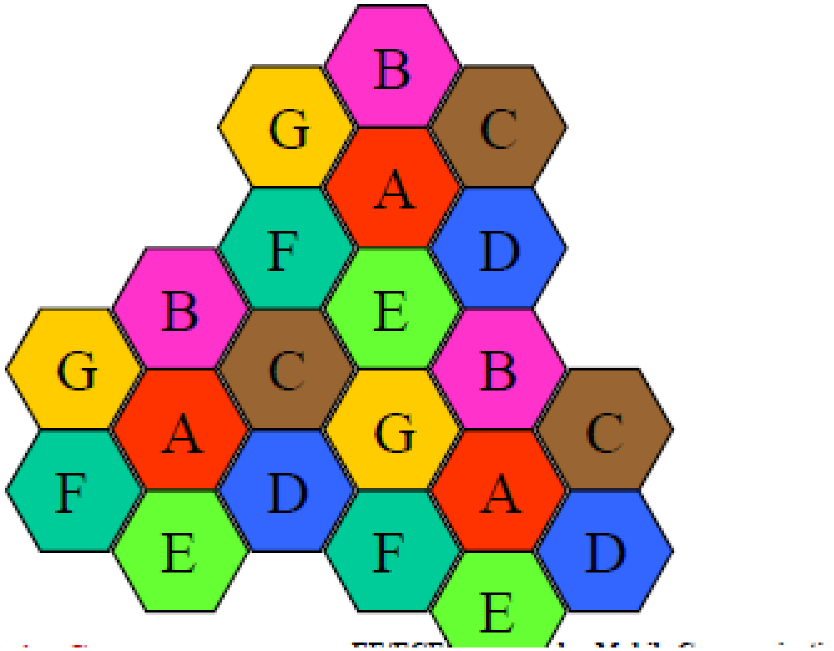
- The Cellular Concept is a system level idea:
  - Each base station is allocated a portion of the total number of channels available to the entire system
  - Nearby base stations are assigned different groups of channels
  - All channels are assigned to a relatively small number of neighboring base stations
- The level of interference between base stations (and the mobile users) is controlled

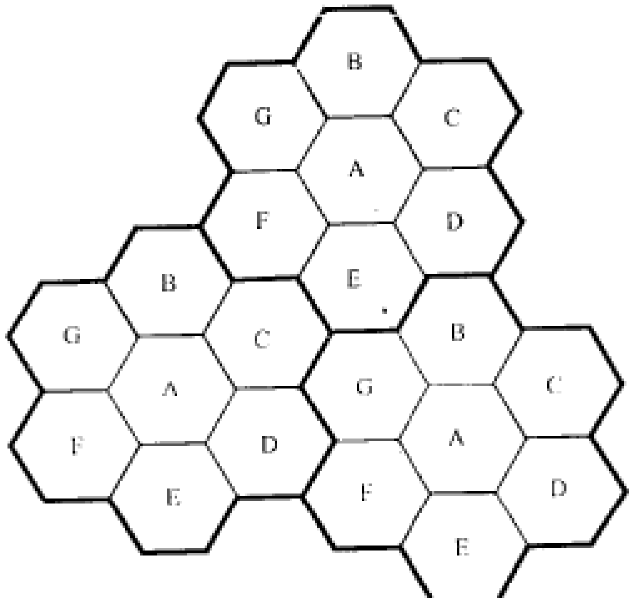
Scalability

- Frequency can be re-used as many times as necessary as long as interference between co-channel stations can be kept within acceptable limits.
- As the demand increases, the number of base stations can be increased (with a corresponding decrease in transmitter power)
- This fundamental principal is the foundation of all modern wireless communication systems.

Frequency Re-use

- The process of selecting and allocating channel groups for all base stations within a system is known as frequency re-use or frequency planning





Comments on Hexagonal Cells

- Hexagon geometry approximates omni-directional base station with free space propagation
- When hexagons are used base stations can either be
  - in the center (center excited) - omni directional antennas or
  - on 3 of the six cell vertices (edge excited) - sectored directional antennas

Simple Calculation

- Let S be the total number of duplex channels
- Let k be the number of channels in each cell
- N cells collectively use the complete set of S available channels.
- N is the *cluster size* (N=4,7 or 12), then $S = kN$
- If a cluster is replicated M times
- Total number of duplex channels $=MS= MkN$
- 1/N is called the *frequency re-use factor*

More About Cellular Structure

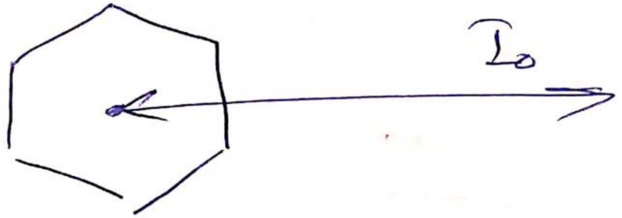
- Each cell has exactly six equidistant neighbors
- Thus there is only certain cluster sizes an cell layouts possible
- It can be shown that the number of hexagonal cells per cluster is given by

$$N = i^2 + ij + j^2$$

- i & j are non negative integers

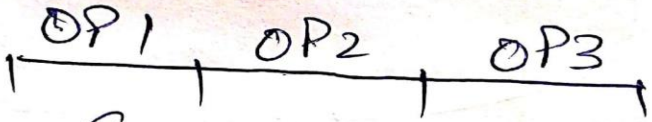
i & j, Co-Channel Neighbors

- To find the nearest co-channel neighbors
- Move *i* cells along any chain of hexagons and then
- Turn 60 degrees counter clockwise, and move *j* cells



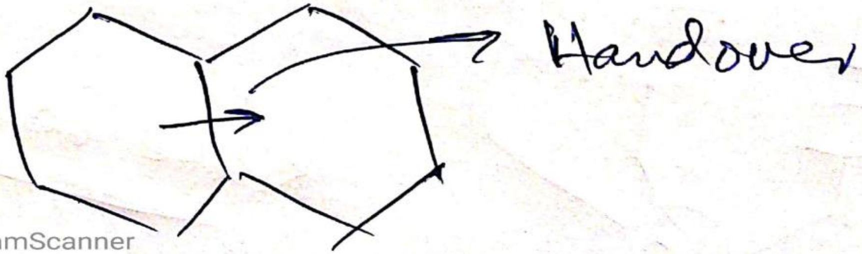
* $SIR = \frac{S}{6 I_0}$ * TIERs

* **Channel Assignment.**



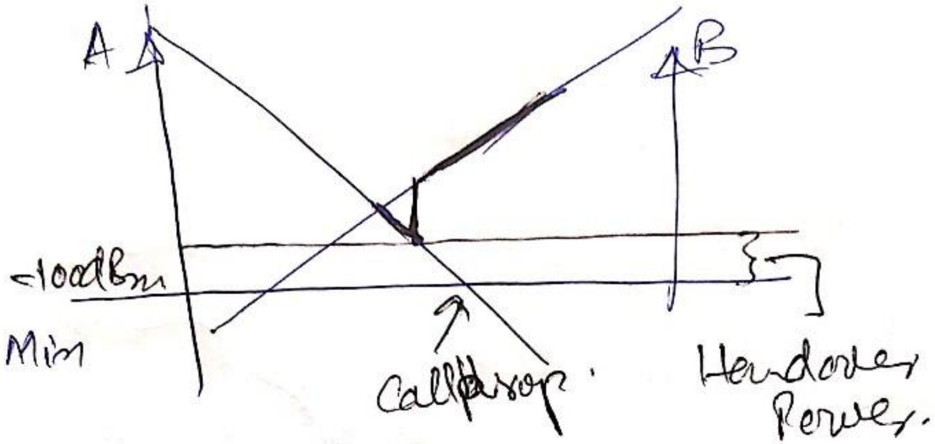
Frequency Spectrum.

* Organizations can do jammers.
* Congestion (No Pair).
* Random access channel not available. (Control channel)



Channel Assignment

- Channel assignment (Frequency reuse)
  - efficient utilization of radio spectrum
  - increased capacity
  - minimized interference
- Channel assignment can be
  - *fixed*
  - *dynamic*
- Affects performance especially *handover* (*handoff*)



$$\Delta = \frac{P_{HO}}{P_{r\,min}}$$

$$\Delta|_{dB} = P_{HO}|_{dBm} - P_{rmin}|_{dBm}.$$

$$P_{rHO} = \Delta \times P_{rmin}.$$

$$\boxed{X_{lin} = 10^{\frac{X_{dB}}{10}}}$$

$$X_{dB} = 10\log(X_{lin}).$$

$\Delta = 0dB \longrightarrow 6dB.$ (1-2 sec).

Fixed Channel Assignment

- Each cell is allocated a predetermined set of channels
- Any call attempt within the cell can only be served by the unused channels in that cell
- Variations that allow channel borrowing exist
  - A cell is allowed to borrow from its neighbor
  - MSC supervises the borrowing procedure

- MSC: Mobile Switching center
- BSC: Base station Center

Implications

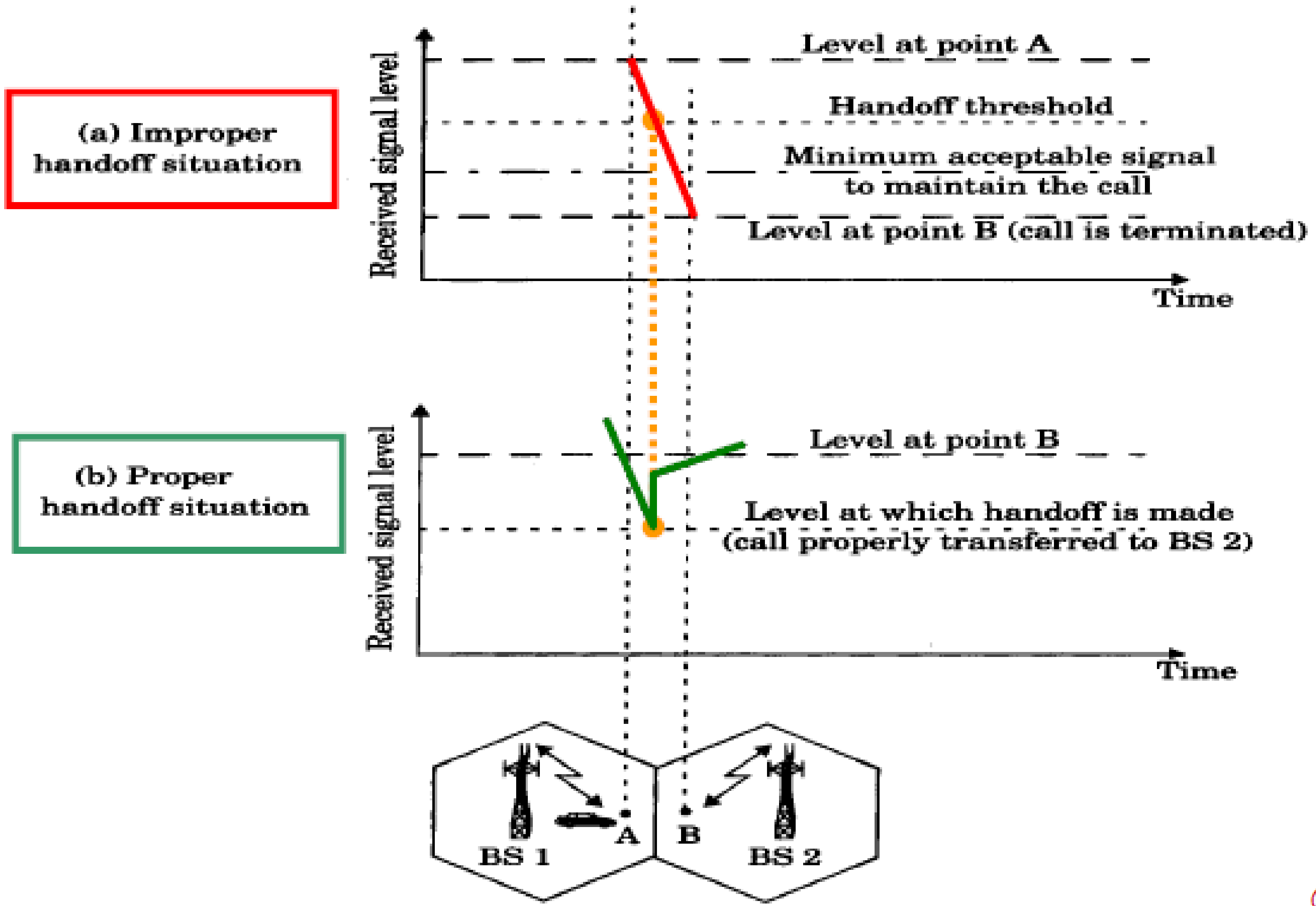
- Dynamic schemes require the MSC to collect real time data on all channels
  - Channel occupancy
  - Traffic distribution
  - Radio signal strength indications (RSSI)
- Makes the MSC more complex, and increases its storage and computational

Handover (Handoff)

- Need to be performed successfully and infrequently as possible and be transparent to users
- Need to decide the optimum signal level to perform handover
- Generally the level is decided the handover level is set slightly above it

$$\Delta = P_{r\ \text{handover}} - P_{r\ \text{minimum usable}}$$

Example



(a) Improper handoff situation
Received signal level
Level at point A
Handoff threshold
Minimum acceptable signal to maintain the call
Level at point B (call is terminated)
Time
(b) Proper handoff situation
Received signal level
Level at point B
Level at which handoff is made (call properly transferred to BS 2)
Time
BS 1
A
B
BS 2

Dwell Time

- The time a call may be maintained within a cell, without handover, is called the *dwell time*.
- Dwell time is dependent on a number of factors
  - propagation
  - interference
  - distance from BS etc.
- Therefore even a stationary subscriber may have a random and finite dwell time

Mobile Assisted Handover (MAHO)

- In analog systems the signal strength was measured by the base station and supervised by the MSC,
- The MSC decides if a handover is necessary or not
- Digital systems handover decisions are mobile assisted
  - Mobile measures signal strength and reports to the serving BS
  - Handover is initiated when power received from the BS of a neighboring cell begins to exceed the power received from the current BS - certain level & duration

Handover 2

- MAHO is faster and more suited for micro cellular environments
- It is also possible to have intersystem handover,
  - Handover from a cell of one MSC to a cell of another MSC
- Numerous issues
  - A local call (initially) may become a long distance call
  - Need to deal with incompatibility of the MSC

Handover Policy

- Ways of handling handover requests
  - Same as all initial call requests
  - Give it higher priority
  - Queue requests
- Generally it is more annoying to have a call cut off in mid conversation than being blocked on a new call attempt
- Fraction of the total available channels in a cell is reserved for handover requests from ongoing calls - *guard channel*

Practical Handover Considerations

- *Cell dragging* - pedestrian users that provide a very strong signal to the BS (LOS), but moved to a close range of another base station causing interference
- Difficulty in obtaining physical cell sites
  - Zoning laws (no high rise structures)
  - Public protest (radiation concerns) e.t.c
- Too many handoffs for high speed mobiles (on a vehicle)

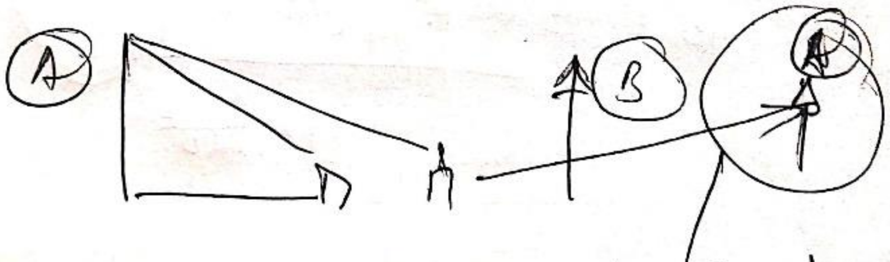
$\Delta = 10 - 20\,dB$ (10 sec).

* Inter-System Handover.
* Heterogeneous System.

For Example Canada.

IP calls.

Cell Dragging.



$\frac{S}{I} \downarrow$

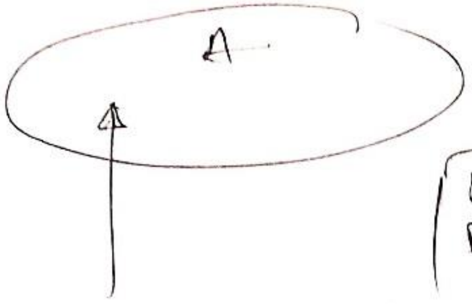
Handoff Improvements

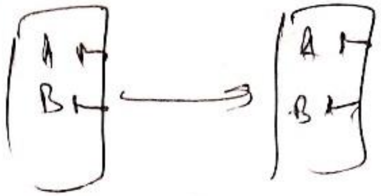
- First generation mobile 10s to make handoff and Δ = 6-12 dB. ($\Delta = P_{r\ \text{handover}} - P_{r\ \text{minimum usable}}$)
- GSM (II generation) 1-2s to make handoff with Δ = 0-6 dB.
- Better system efficiency and handling high speed vehicles

Soft Handoff

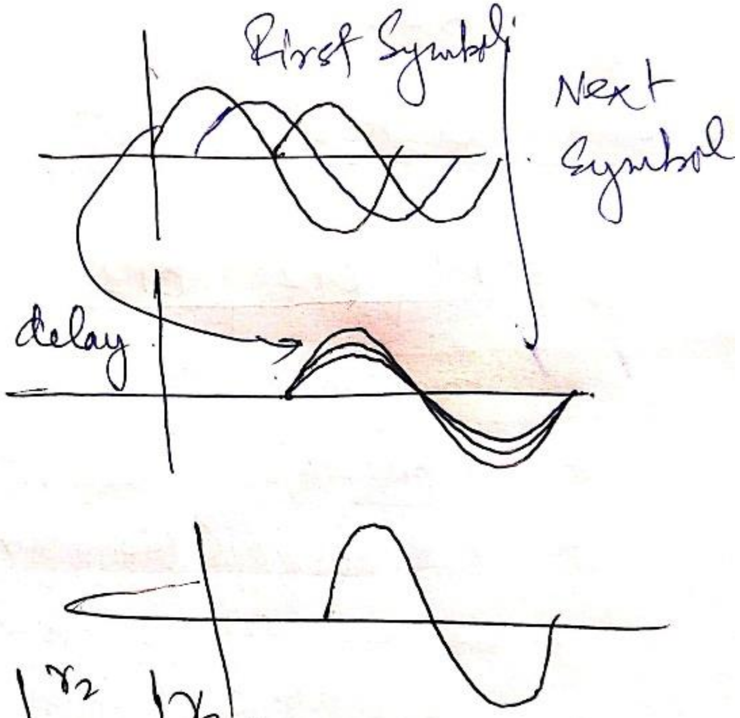
- Channelized wireless systems (such as GSM) have to switch channels in the process of handoff
- There is always risk of losing the connection
- IS-95, Code Division Multiple Access (CDMA) system provides ***Soft Handoff***.
- ***Soft Handoff*** does not mean changing the channel but rather deciding which base station will handle the connection
- This is a unique property of CDMA concept.

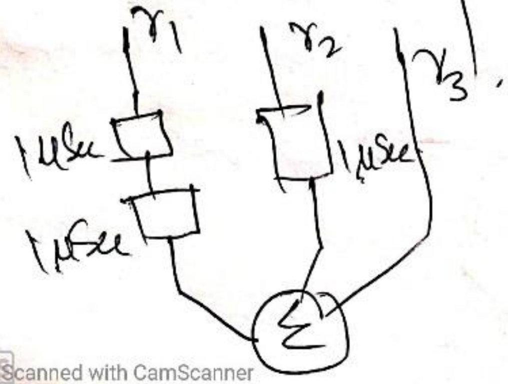
Soft & hard Handovers.





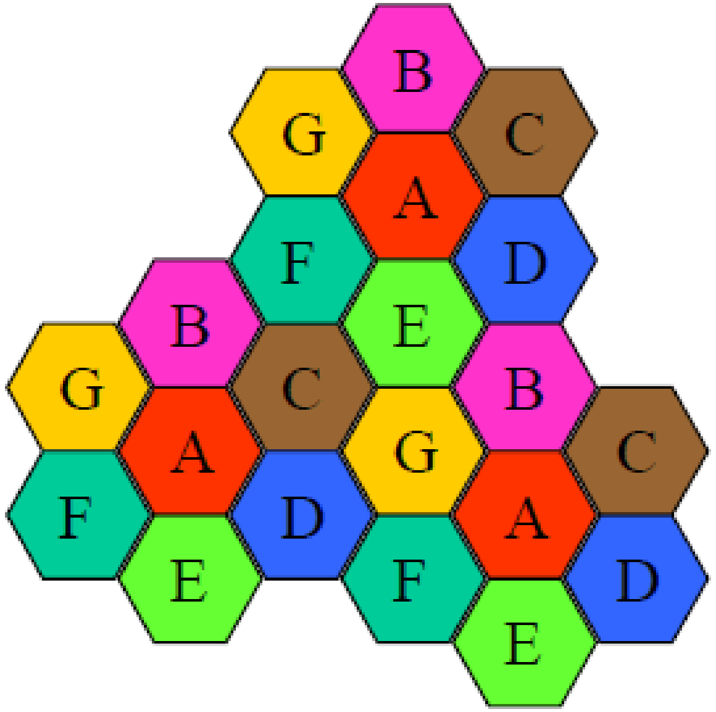
CDMA:

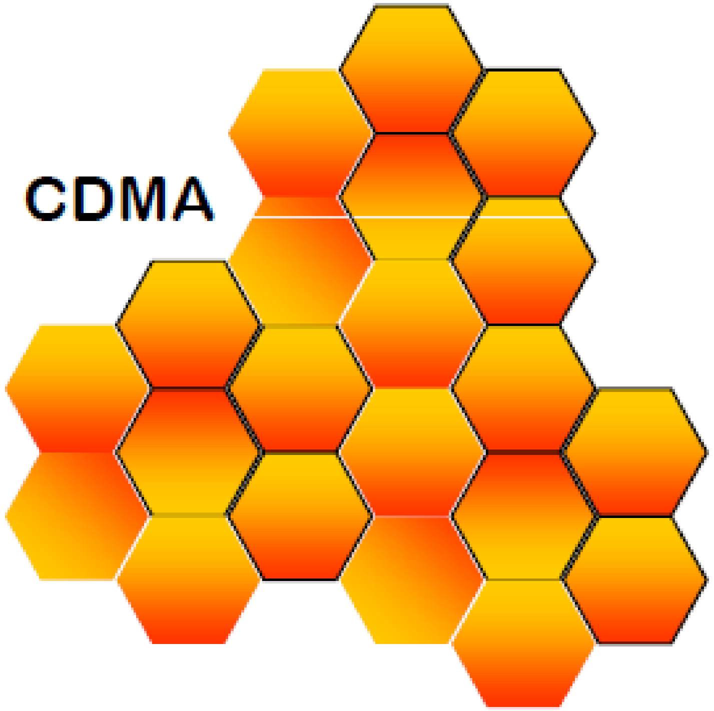




Rake Receiver

CDMA Frequency Reuse Pattern





Co-channel Interference

- There are several cells that use the same set frequencies
  - co-channel cells
- Interference between signals from these cells is called co-channel interference
- Unlike thermal noise, this cannot be overcome by increasing the signal power
- The co-channel cells must be physically separated

Co-channel Interference

- Because the cell size is same, co-channel interference is independent of transmitted power
- It is a function of the radius of the cell (R), and the distance to the center of the nearest co-channel cell (D)
- For hexagonal geometry, co-channel reuse ratio Q is given by

$$Q = \frac{D}{R} = \sqrt{3N}$$

$$N = KBFT \qquad F = 1-10$$

$$F = 6\ dB$$

$$B = 1 \times 10^6\ Hz$$

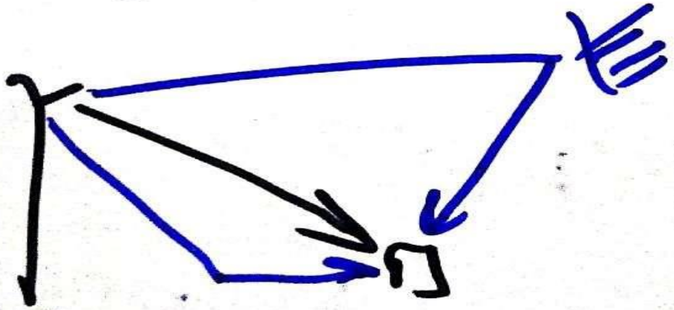
$$\frac{S}{N} = \frac{1mW}{10^{-10}mW}$$

$$= 10^{10}$$

$$SNR = S/dBm - N/dBm$$

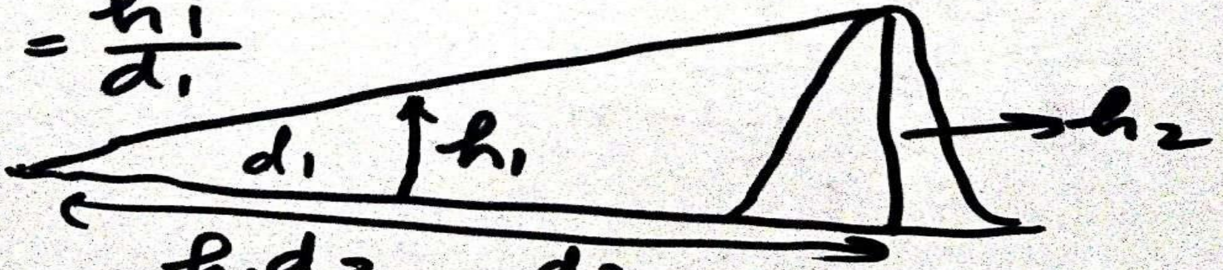
$$SNR = 0dBm - 100dBm$$

$$SNR = -100dB$$

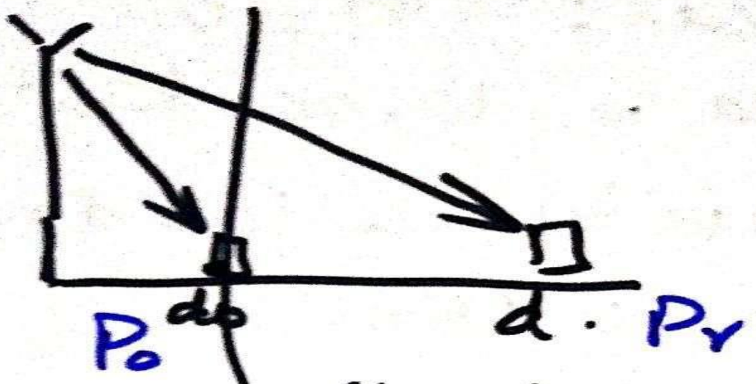


$$P_r \propto \frac{P_t}{d^n}$$

$$\frac{h_2}{d_2} = \frac{h_1}{d_1}$$



$$h_2 = \frac{h_1 d_2}{d_1}$$



close in reference

$$P_0 \propto \frac{P_t}{d_0^n} \qquad P_0 = const\,\frac{P_t}{d_0^n}$$

$$P_r \cancel{\propto} const\,\frac{P_t}{d^n}$$

$$\frac{P_r}{P_0} = \frac{\cancel{const} \times \cancel{P_t}/d^n}{\cancel{const} \times \cancel{P_t}/d_0^n}$$

$$\frac{P_r}{P_0} = \frac{d_0^n}{d^n} = \left(\frac{d_0}{d}\right)^n.$$

$$P_r = P_0\left(\frac{d_0}{d}\right)^n$$

Numerical: $n = 4$

Area = 10,000 Km^2

Sensitivity = -100 dBm

P_0 = 10 dBm

d_0 = 10 m

How many base Stations = ?

$$A_c = \frac{3\sqrt{3}}{2} R^2$$

$$\# \text{ of cells} = \frac{10,000}{A_c} = 100.4$$

* Is it beneficial that the value of "n" is more?

$$\left(\frac{S}{I}\right) \quad I_0 \propto 1/d^2 = \frac{1}{100}$$

$$I_1 \propto \frac{1}{d^4} = 1/10,000$$

Scanned with CamScanner

$$\frac{S}{I} \propto Q^{n}.$$

$$\frac{S}{I} \propto \left(\frac{D}{R}\right)^{n} = \frac{R^{-n}}{D^{-n}}$$

$$\frac{S}{I} = \frac{R^{-n}}{6D^{-n}} = \frac{R^{-n}}{\sum_{k=1}^{K} 6k\, D_k^{-n}}.$$

$$D_k = kD.$$

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{k=1}^{K} 6k(kD)^{-n}}$$

$$= \frac{\left(\sqrt{3N}\right)^{-n}}{6\sum_{k=1}^{K} k^{1-n}}$$

$$\boxed{D = R\sqrt{3N}}$$

If noise figure of a mobile receiver is mersured to be 10dB. Find SINR while considering 3-tiers of interference cells and 7 cell cluster, assume 'n' is 4, where $S = 1mW$

0dBm

$$\frac{S}{I+N} = ?$$

$$\frac{S}{I} = ? \qquad I = \_\_\_\_$$

$N = KBFT$.

Carrier to Interference Ratio

- Carrier to Interference ratio (SIR or S/I) is also independent of transmitted power
- It is a function of the radius of the cell (R), and the distance to the center of the nearest co-channel cell (D)
- For the first tier in hexagonal geometry, Carrier to Interference ratio is usually taken as

$$\frac{S}{I} \approx \frac{1}{6}\left(\frac{D}{R}\right)^4 = \frac{1}{6}(3N)^2$$

Some Arithmetic Again

- Let i_0 be the number of co channel interfering cells
- then carrier signal to interference ratio (SIR)

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

- S - desired signal power from desired BS; I_i - interference power caused by the i^{th} interfering co-channel cell BS

Received Power

- Ave. received signal strength at any point decays as a power law of the distance of separation (*d*) and is given by

$$P_r = P_0\left(\frac{d}{d_0}\right)^{-n}$$

$$P_r(dBm) = P_0(dBm) - 10n\log\left(\frac{d}{d_0}\right)$$

- P_0 - Power received at a close-in reference point in the far field region of the antenna at a small distance; n - path loss component (2-4)

SIR

– If D_i is the distance of the i^{th} interferer, the received power at a given mobile due to the i^{th} interfering cell will be proportional to $(D_i)^{-n}$
– When the transmit power of each BS is equal and the path loss exponent is the same

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

Simpler SIR

– Considering only the first layer of interfering cells & if all these BS are equidistant

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

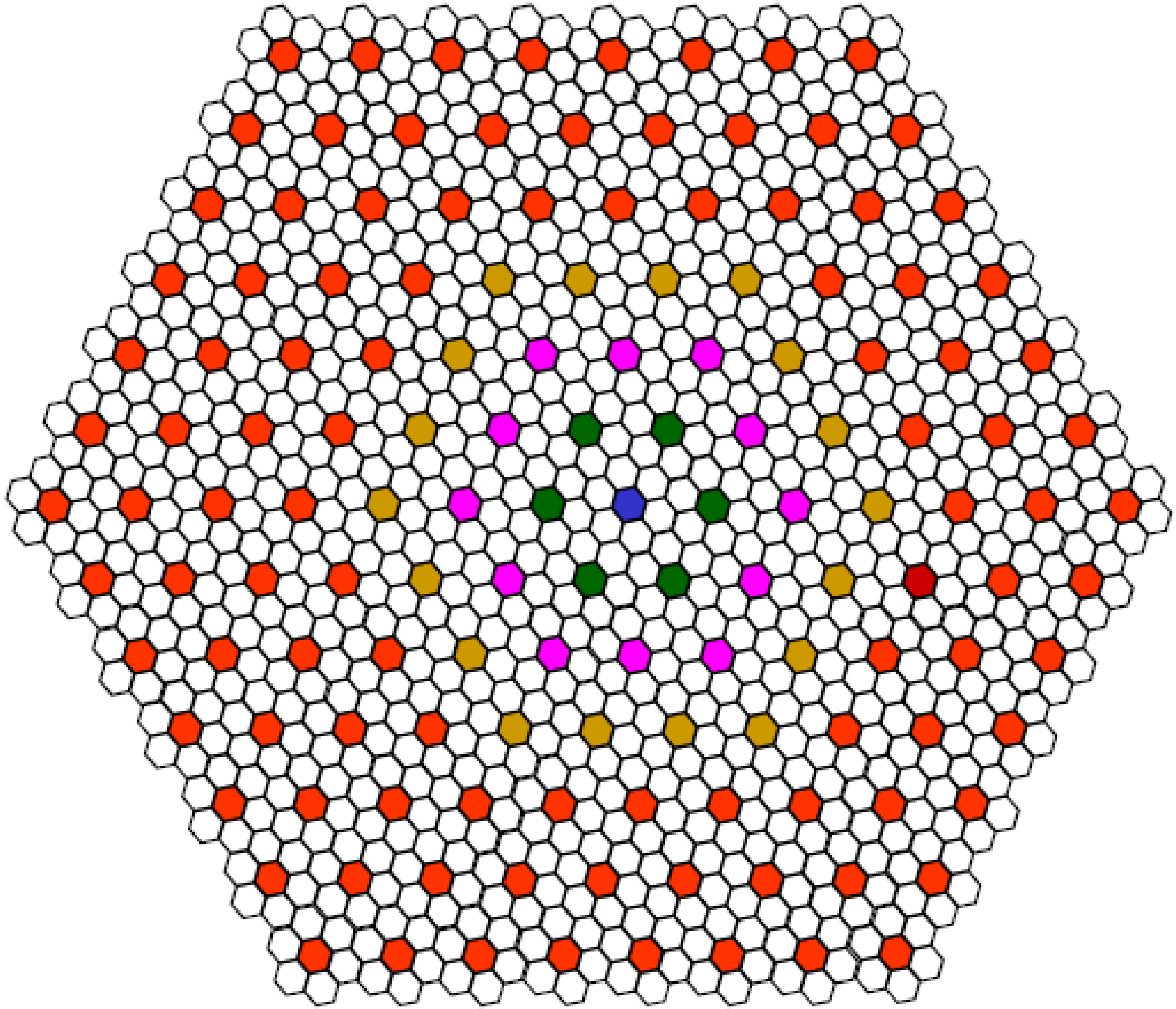
– i_0 - number of neighboring/interfering co-channel cells

Interference Limitation Example

- $i_0 = 6$ number of co-channel cells
- $N = 7$
- $n = 2$

$$\frac{S}{I} = \frac{3N}{6} = \frac{N}{2}$$

- Considering only the first layer of interfering cells & if all these BS are equidistant



$1 \rightarrow 6$

$2 \rightarrow 12$

$3 \rightarrow 18$

$\cdots$

$k \rightarrow 6k$

Interference Limitation

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

$$D_K < kR\sqrt{3N}$$

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{k=0}^{K} 6 \cdot k(kR\sqrt{3N})^{-n}}$$

$$\frac{S}{I} = \frac{(\sqrt{3N})^{n}}{6 \cdot \sum_{k=0}^{K} k^{1-n}}$$

Interference Limitation

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{6 \cdot \sum_{k=0}^{K} k^{1-n}}$$

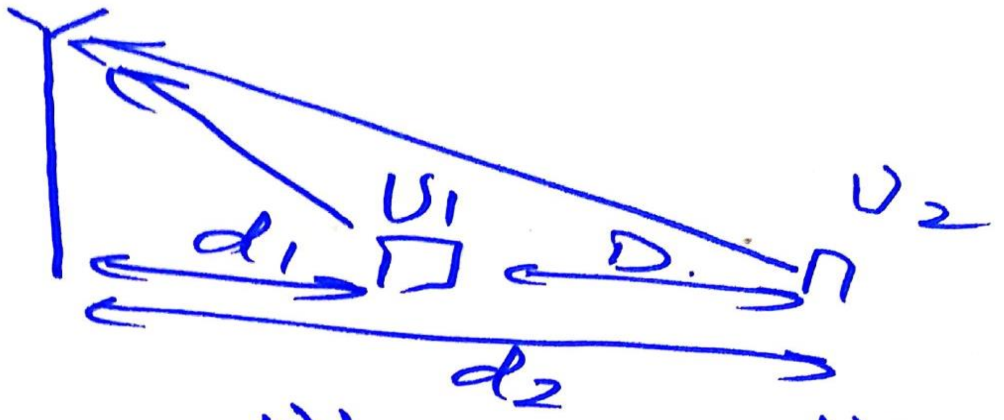
– Considering *K* layers of interfering cells

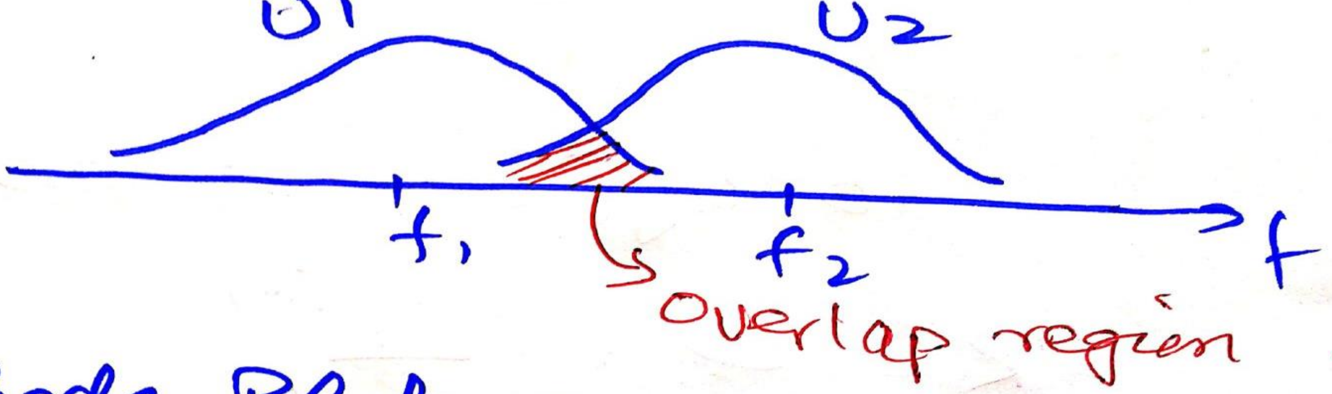
– For *N* fixed, *n=2* and the number of layers K→∞; S/I →0

$$I = \lim_{K \to \infty} O\left(\sum_{k=0}^{K} \frac{1}{k}\right) = \infty$$

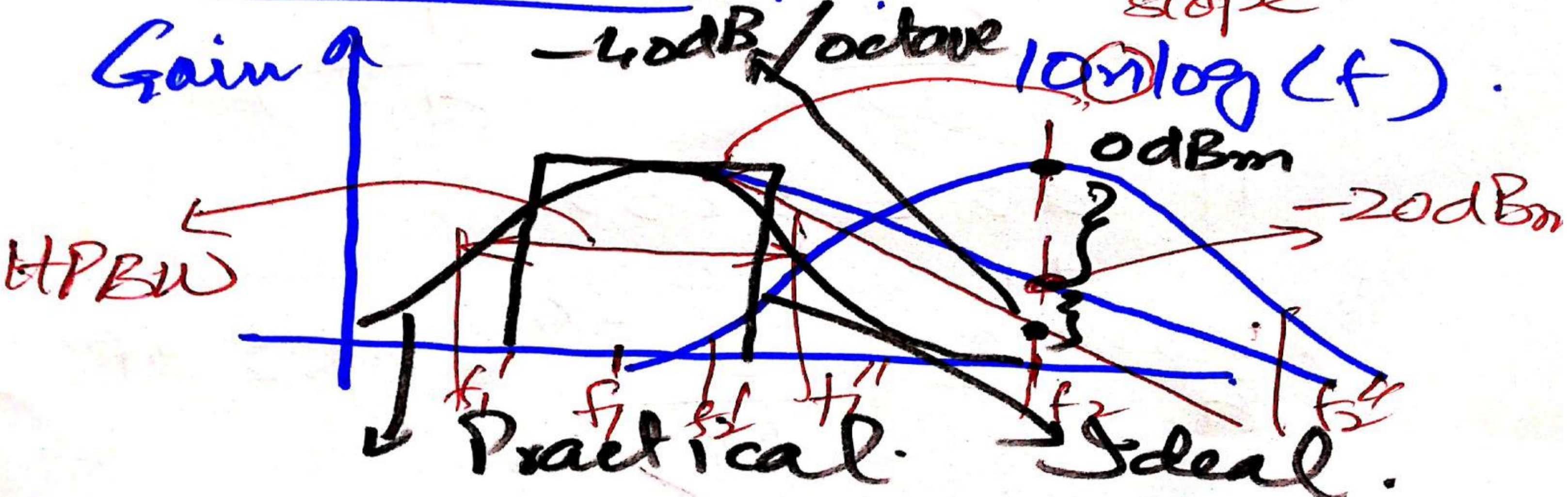
Adjacent Channel Interference 1

- Interference resulting from signals which are adjacent in frequency
- Results from imperfect receiver filters which allow nearby frequencies to leak
  - Particularly serious if an adjacent channel user is transmitting very close to the a receiver
- Referred to as the *near-far* effect
  - Nearby transmitter captures the receiver


U1
U2
d1
D
d2


U1
U2
f1
f2
f
overlap region

Bode Plot ?


Gain
-40dB/octave
slope
10n log(f)
0dBm
-20dBm
HPBW
Practical
Ideal

$$SNR = 0dBm - (-20dBm).$$
$$= 20dB.$$
$$10^{20/10} = 100.$$
$$SNR = 100.$$

Half Power Band width.

$$10\log\left(\frac{1}{2}\right) = -3dB.$$

$$SIR = Q^{n} = \left(\frac{D}{R}\right)^{n}.$$
$$= \left(\frac{R}{D}\right)^{-n} = \left(\frac{d_2}{d_1}\right)^{-n}.$$

if $d_2 = 200m$.
$d_1 = 10m$.

$$\left(\frac{d_2}{d_1}\right)^{-n} = \left(\frac{200}{10}\right)^{-4} = -52dB.$$

Adjacent Channel Interference 2

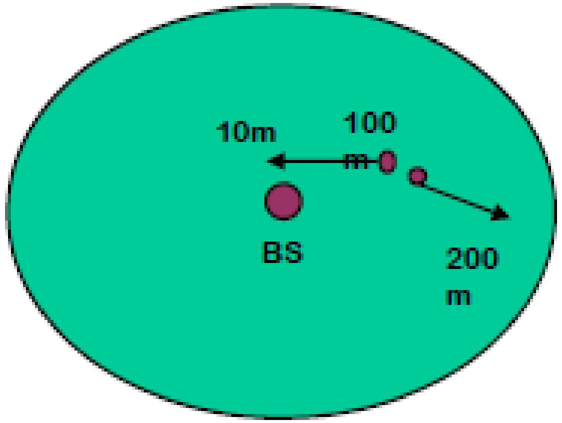
- Can be minimized by careful filtering & channel assignment
- If the frequency re-use factor is small, the separation between adjacent channels may not be sufficient to keep the adjacent channel interference level within tolerable limits

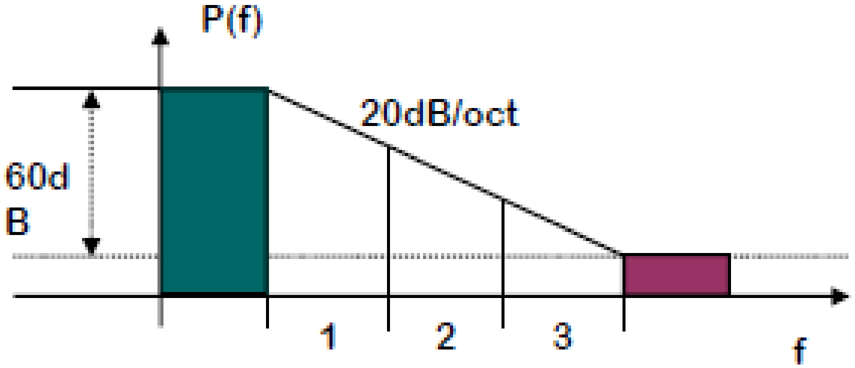
Adjacent Channel Interference 3

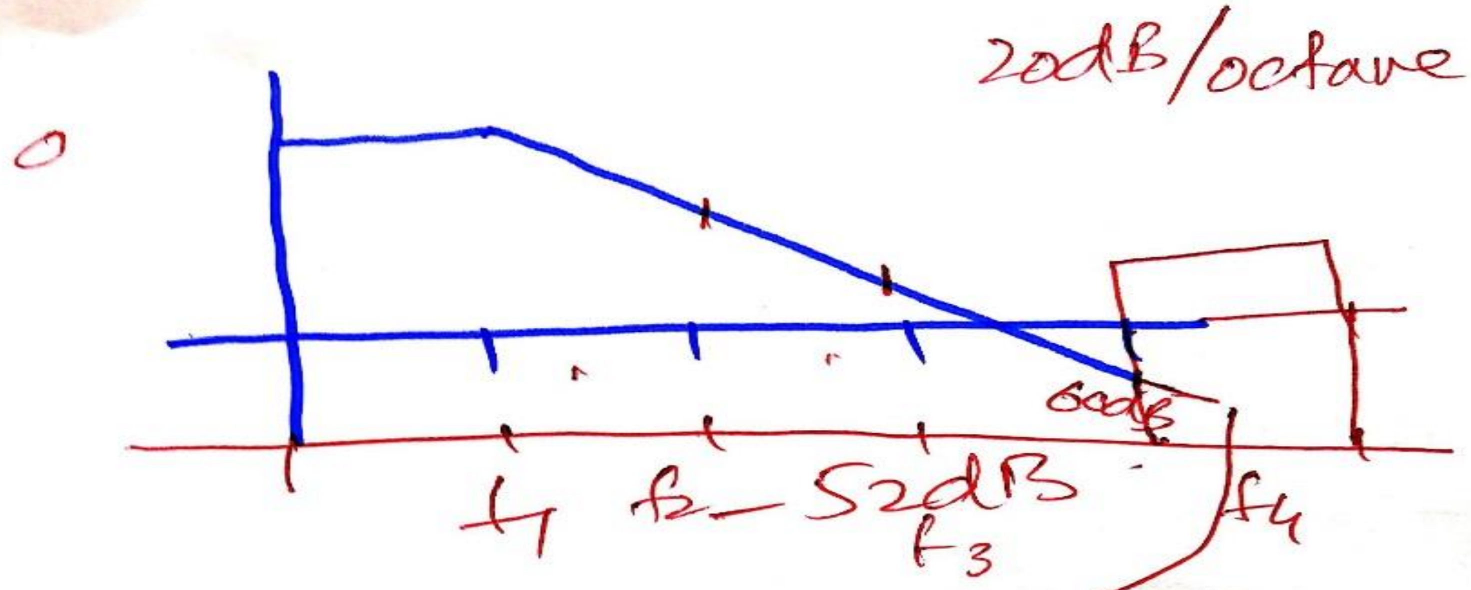
- If a mobile is 20 times closer to the BS than another mobile

$$SIR = (20)^{-n}$$

- For n= 4, this is equal to -52 dB
- If the intermediate filter has a slope of 20 dB/octave in the stop-band
- Adjacent channel must be displaced 3 times the pass-bandwidth from the center of the receiver frequency band-pass to achieve the 52 dB attenuation







We can Place channel.
Here 3.

Power Control

- The power level transmitted by every mobile is controlled by the BS
- Enables to use the smallest power to maintain good link quality and reduces interference to other cells
- Increases battery lifetime before recharging (talk time and stand-by time)
- CDMA requires very strict power control (1dB)

Trunking

- Trunking is a statistical concept which allows a large number of users to share relatively small number of channels providing access on demand from a pool of available channels.
- Relatively small number of channels can serve a large number of users since all users are not demanding access and utilization of the system at the same time

Grade of Service

- ***Grade of Service*** is a measure of the ability of a trunked system to give access to a user requiring service during the busiest hour (4-6pm, Thu, Fri)
- Grade of Service is usually measured in two ways
  1. Probability that a call is blocked
  2. Probability that a call will be delayed more than specified queuing time (some tolerable delay)

Some Traffic Quantities

- A_u - Traffic intensity

$$\boxed{A_u = \lambda \; H}$$

- H - average duration of a call
- λ - average number of calls per unit time
- For system with U, users total offered traffic intensity A, is

$$\boxed{A = U A_u}$$

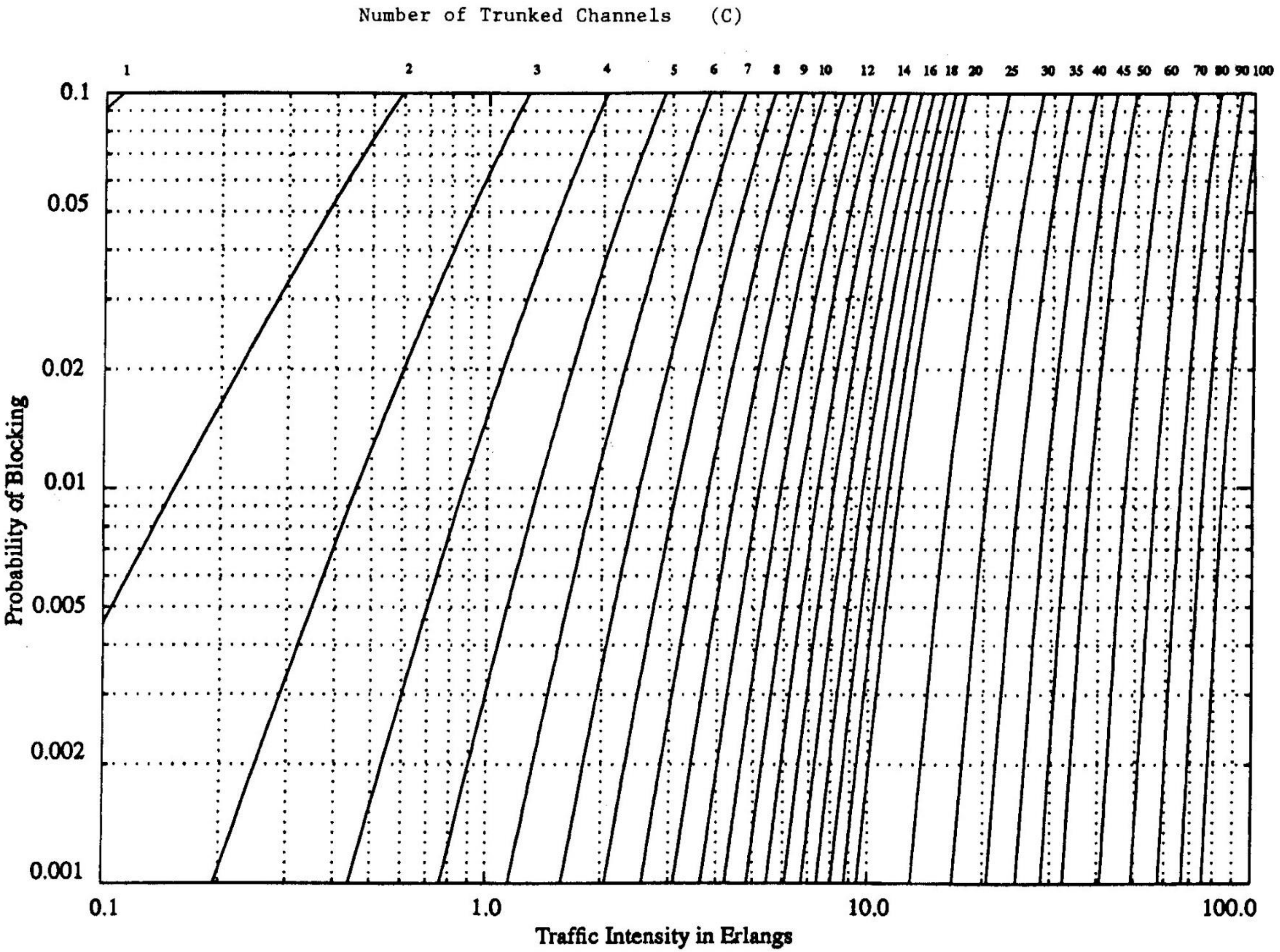
Blocked Calls Cleared

- Calls arrive as Poisson distributed
- All users may request service at any time
- A - generated traffic
- C - number of channels
- Grade of Service (Erlang B formula):

$$GOS = \Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}}$$

Capacity of Erlang B System

	Capacity in Erlangs for GOS			
No.of Channels	Pr=0.01	0.005	0.002	0.001
2	0.153	0.105	0.065	0.046
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
40	29.0	27.3	25.7	24.5
100	84.1	80.9	77.4	75.2



The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

Erlang C Chart

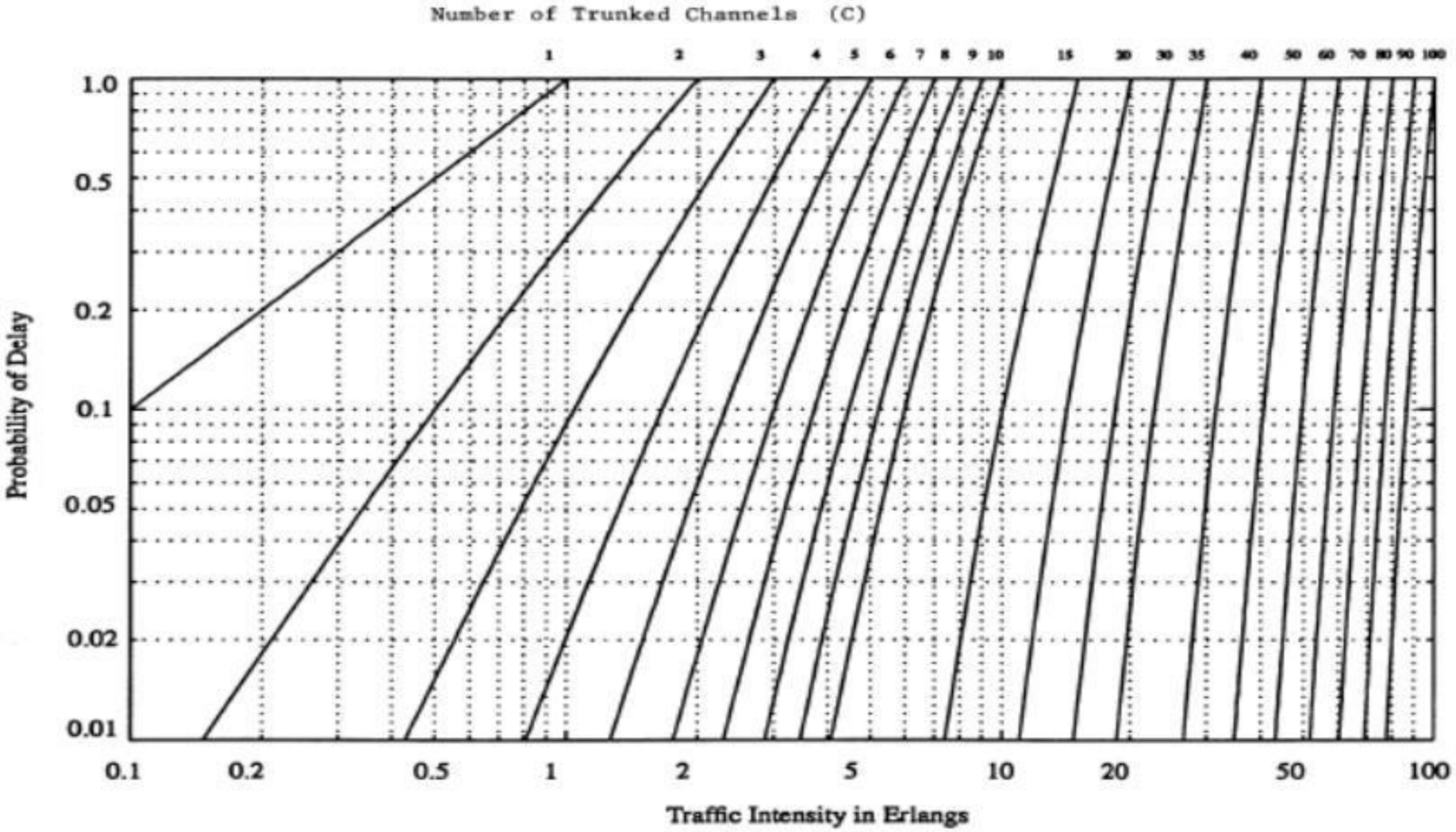


Figure 3.7 The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Blocked Calls Delayed

- If a channel is not available immediately the call request may be put in a queue and delayed until a channel becomes available
- Erlang C formula:

$$\Pr[delay > 0] = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1}\frac{A^k}{k!}}$$

Grade of Service for Delayed Calls

$$GOS = \Pr[delay > t]$$

$$= \Pr[delay > 0]\Pr[delay > t \mid delay > 0]$$

$$= \Pr[delay > 0]\ e^{-\frac{(C-A)t}{H}}$$

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.

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.

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, and (g) the theoretical maximum number of users that could be served at one time by the system.

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 = 1 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?

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

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

Average Delay in a Queued System

- The average delay D for all calls in a queued system is:

$$D = \Pr[\, delay > 0\,] \frac{H}{C - A}$$

  - Where the average delay in the queue is H/(C-A)
    - H – average duration of a call
    - C – number of channels
    - A – total offered traffic

Shannon Capacity.

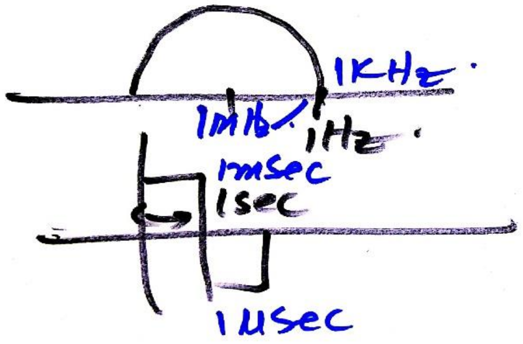
$C = B \log_2(1 + SNR)$.

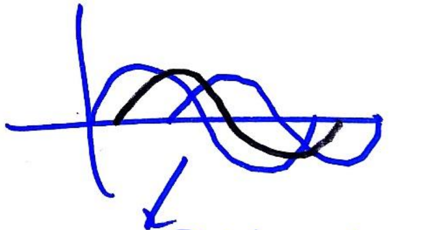
C = bits/sec/Hz.

C = bits/sec

$BER = 1/10^{10}$ or $\frac{1}{10^{100\ldots0}}$

$C \propto$ Band.





$x \longrightarrow \boxed{h} \longrightarrow y = x \circledast h$

$Y = X \times H$

dB's $P_i = 2W$ —[G]— $P_o = 4W$.

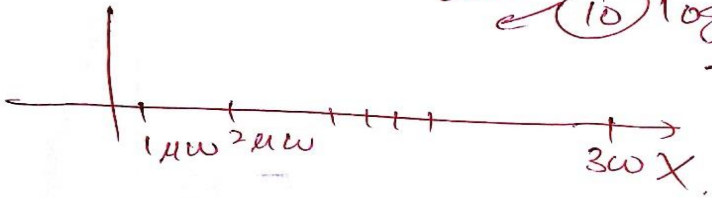
$G = \frac{4W}{2W} = 2$.

dBW , dBm. 2000 mW

deci — (10) log (1 μW). Graham Bell.

−6 BW.

−60 dBW.



$10\log(10) = 10\,dBW$.

−60 dBW to 10 dBW.

* France & Singapore. 1Kg sample.

↳ Reference S

* Sher Shah Soori. Sair.

Sarsadhi (trees, in 5 year Government).

Delhi (Precise Units).

$* \; G = \frac{P_o}{P_i} = \frac{V_o^2}{V_i^2} = \frac{i_o^2}{i_i^2} = \frac{a_o^2}{a_i^2}$

$G|_{dB} = 10\log\left(\frac{P_o}{P_i}\right) = 20\log\left(\frac{a_o}{a_i}\right)$.

Gain can be −ve or

2W ⟶ $10\log(2) = 3\,dBW$

2000 mW ⟶ $10\log(2000) = 33\,dBm$.

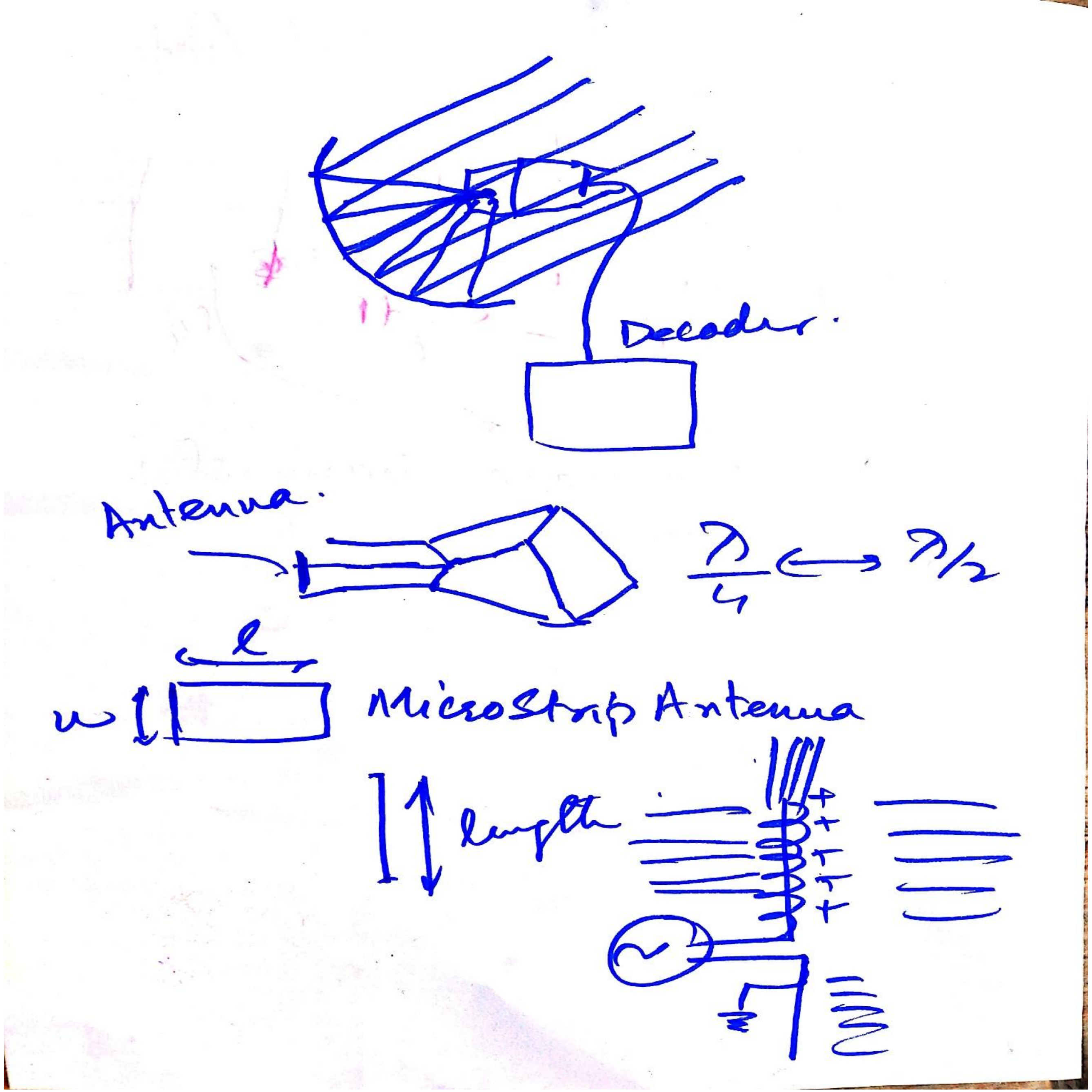
dBm = dBW + 30

dBW = dBm − 30.

P = −60 dBm

P = −60 dBm − 30

P = −90 dBW.


Decoder.
Antenna.
$\frac{\lambda}{4} \longleftrightarrow \lambda/2$
l
w
Microstrip Antenna
length