The Cellular Concept-
System Design Fundamentals

Outline

- Cellular Concept
- Frequency Reuse
- Handoff Strategies
- Interference and System Capacity
- Channel assignment
- Trunking and Grade of Service
- Improving Coverage and Capacity in Cellular Systems

Cellular Concept

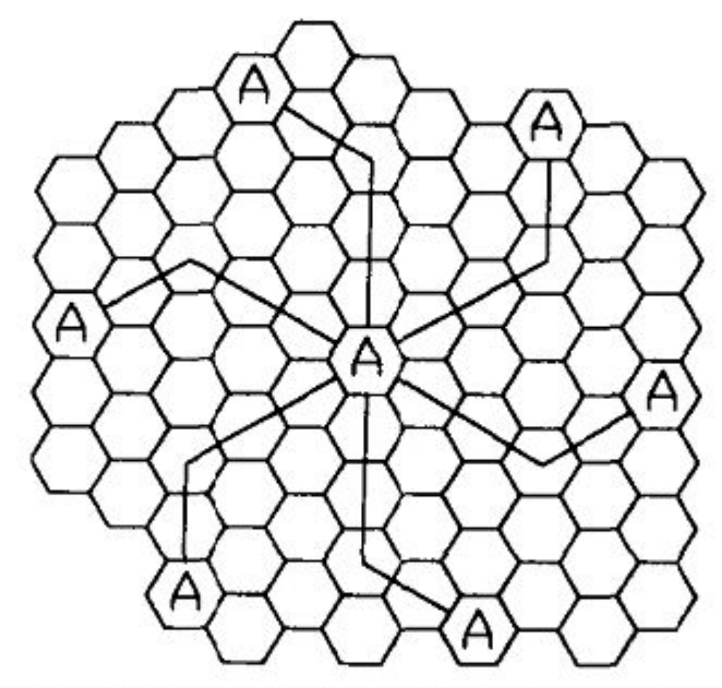
- The total coverage area of cellular radio systems is divided into smaller geographic area called cell
- The base station for that cell is allocated a number of radio channel to be used only within that cell
- Hexagon is a better choice for cell because they can cover the geographic region with the fewest number of cells rather than square or triangle.
- Hexagon also closely approximates a circular radiation pattern which would occur for an Omnidirectional antenna.

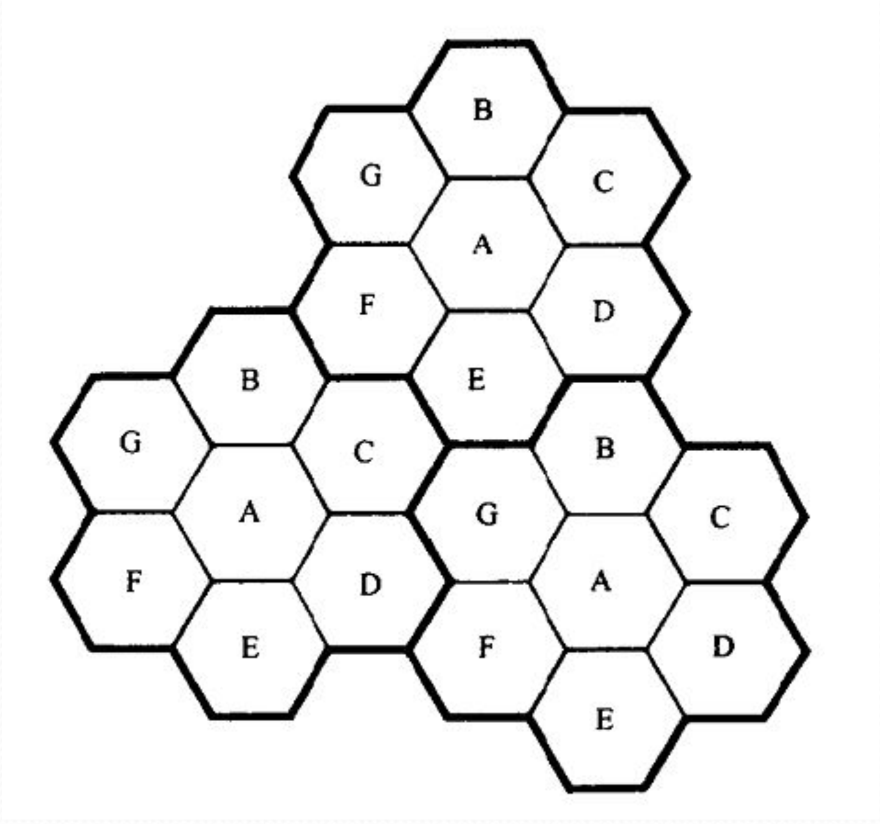
Frequency Reuse

- Base stations in adjacent cells are assigned channel groups which is completely different than neighboring cells
- The base station antennas are designed to achieve the desired coverage within a particular cell
- By limiting the coverage area within the boundaries of a cell, the same group of channels may be used to cover different cell that are separated from one another by keeping the interference level within tolerable range. This is called ***Frequency Reuse***

Frequency Reuse (cont'd)

- The N cells which collectively use the complete set of available frequencies is called a ***Cluster***.
- *N = 19. i=3, j=2.*





Frequency Reuse (cont'd)

- Consider the following
  - k = The group of channels allocated to each cell
  - N = Number of cells in a cluster
- Then Total number of available radio channels, $\boldsymbol{S = kN}$
- Again if a cluster is M times repeated

  Then Total number of duplex channels, $\boldsymbol{C = MkN = MS}$
- Cluster size is represented by N and is typically 3, 7, 12 or 13 based on the formula $\boldsymbol{N = i^2 + ij + j^2}$

Example #1

- A 30 MHz spectrum is allocated to a wireless 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 the that system uses 7-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 of that system
- Answer:

Total bandwidth = 30 MHz

Channel bandwidth = 25 KHz X 2 simplex channels = 50 KHz/duplex channels

Total available channels = 30,000/50 = 600 Channels = S

As N = 7, total number of channels available per cell,

$$k = S/N = 600/7 \approx 85 \text{ Channels}$$

Example #1 (cont'd)

- A 1 MHz spectrum for control channels implies that there are 1000/50 = 20 Control Channels out of the 600 channels available.
- To evenly distribute the control and voice channels, simply allocate the same number of voice channels in each cell wherever possible.

For N = 7, total number of voice channels = (600-20) / 7

= 82 Voice Channels

4 cells with 3 control channels and 82 voice channels

3 cells with 2 control channels and 83 voice channels

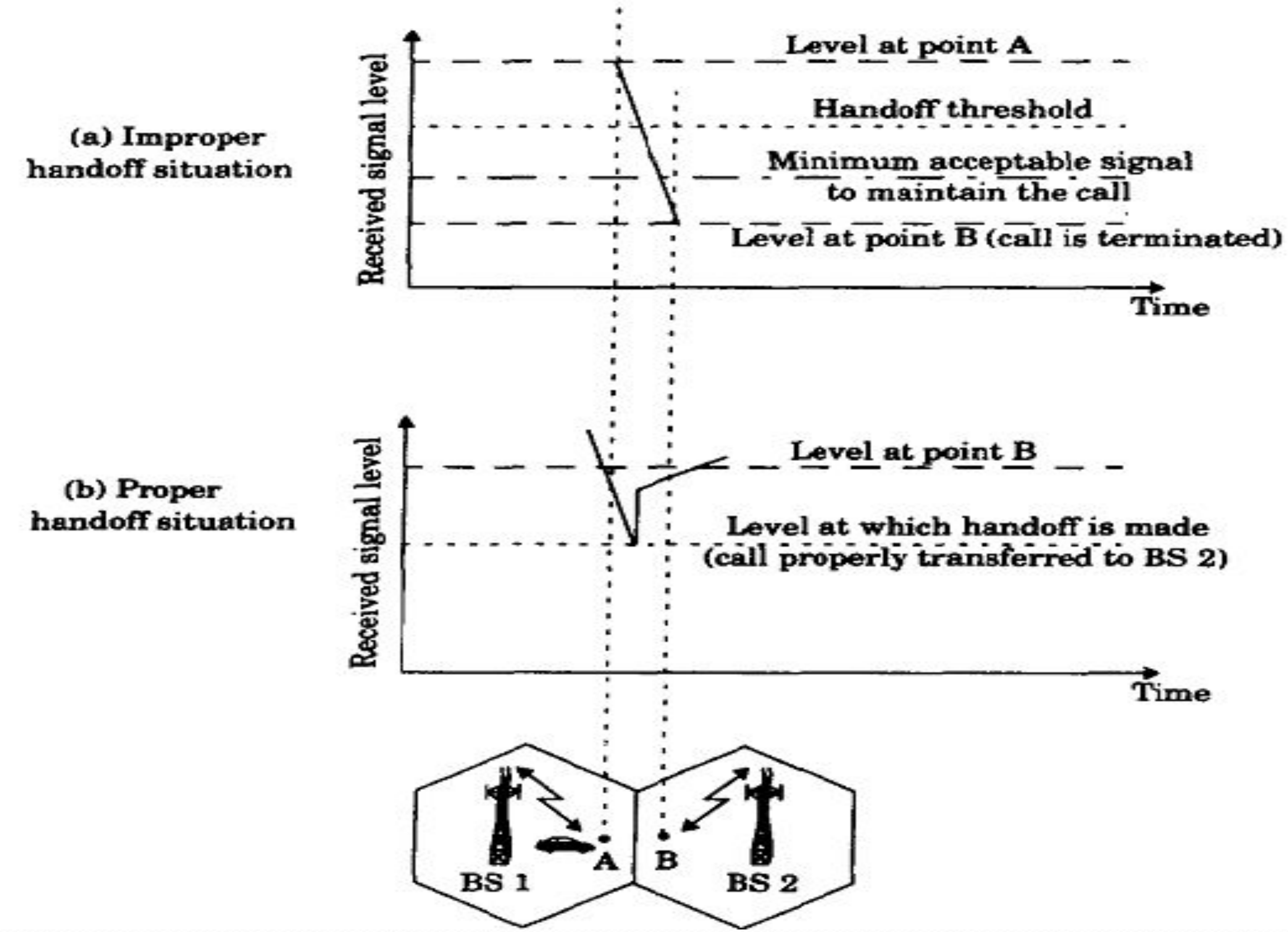
Channel Assignment strategies

- Fixed Channel Allocation (FCA)
  - fixed number of channels are permanently allocated to each cell.
  - If all the channels of that cell are occupied, then any new call attempt will be blocked
- Dynamic Channel Allocation (DCA)
  - Channels are not permanently allocated to the cell
  - One cell can borrow channels from the neighboring cell if needed.
  - MSC requires channel occupancy, traffic distribution and *Radio Signal Strength Indications* (RSSI) data for managing dynamic allocation of channels

Handoff Strategies

- When a mobile moves into a different cell while a conversion is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station. This is called handoff.
- A slightly stronger signal level than the minimum acceptable signal level (usually -90 dBm and -100 dBm) is used as a threshold at which handoff is made.
- Definitions of terms like Hard handoff, Soft Handoff, *Locator Receiver*, *Mobile Assisted Handoff* (MAHO), *Intersystem Handoff*

Handoff Strategies (cont'd)

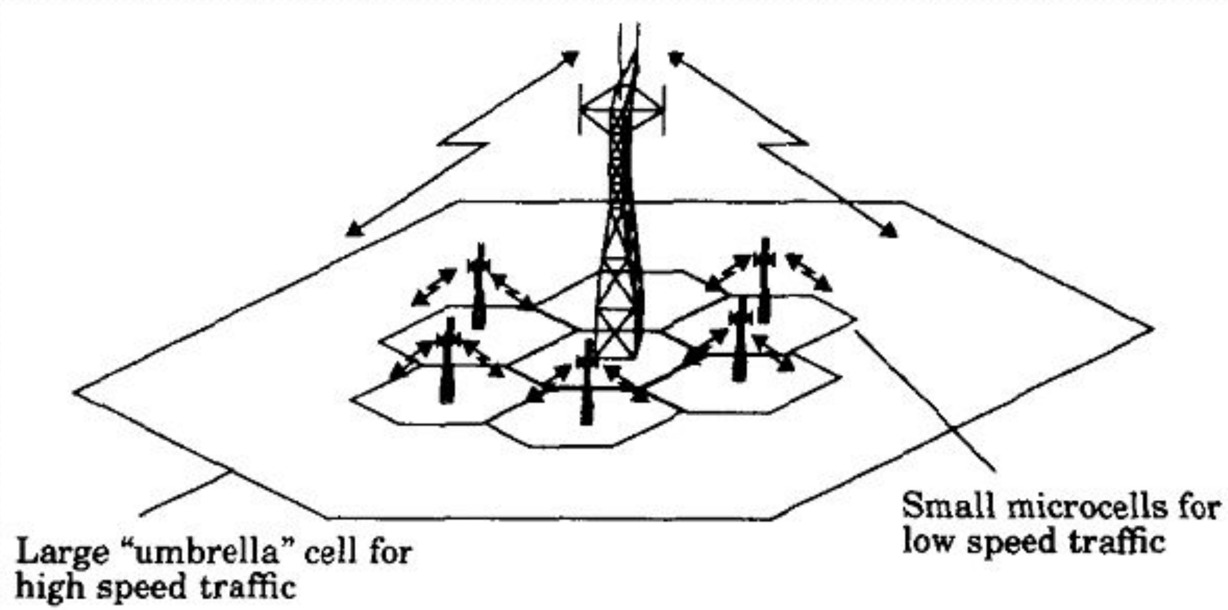


Prioritizing Handoffs

- Guard channel concept
  - A fraction of the total available channels in a cell is reserved for handoff requests, known as guard channels
  - It reduces the total carried traffic but it also reduces forced terminations of the ongoing calls that will irritate the users.

Practical Handoff Considerations

- High speed vehicles pass through the coverage region within a matter of seconds whereas pedestrian users may never need a handoff during a call
- Umbrella Cell approach
- Cell dragging



Interference and System Capacity

- Interference may happen because of another mobile in the same cell, a call progress in the neighboring cell, other base station operating in the same frequency band, or from any other noncellular system

- Interference is recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls

- **Co-channel interference** → From the cell using same frequency
- **Adjacent Channel interference** → From frequencies adjacent to the desired signal frequency

Co-channel interference

- Unlike thermal noise which can be overcome by increasing the SNR, co-channel interference cannot be combated by increasing the carrier power. Rather it will increase the interference

- To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation

- Co-channel reuse ratio, $Q = \frac{D}{R} = \sqrt{3N}$

  where R = Cell Radius

  D = Distance between centers of nearest co-channel cells

Co-channel interference

- A small value of Q provides larger capacity since cluster size is small whereas a large value of Q improves quality as con-channel interference is reduced

Cluster Size,

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

Table 2.1 Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

- Let i_0 be the number of co-channel interfering cells.
- Then the Signal-to-Interference (S/I or SIR) is

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

where S is the desired power level and

I_i is the interference power caused by ith

co-channel base station

Co-channel interference

- When the transmit power of each base station is equal and the path loss exponent *(n)* is same throughout the coverage area, *S/I* can be given as

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

- Considering only the first layer of interfering cells, if all the interfering base stations are equidistant *(D)* from the desired base station, then

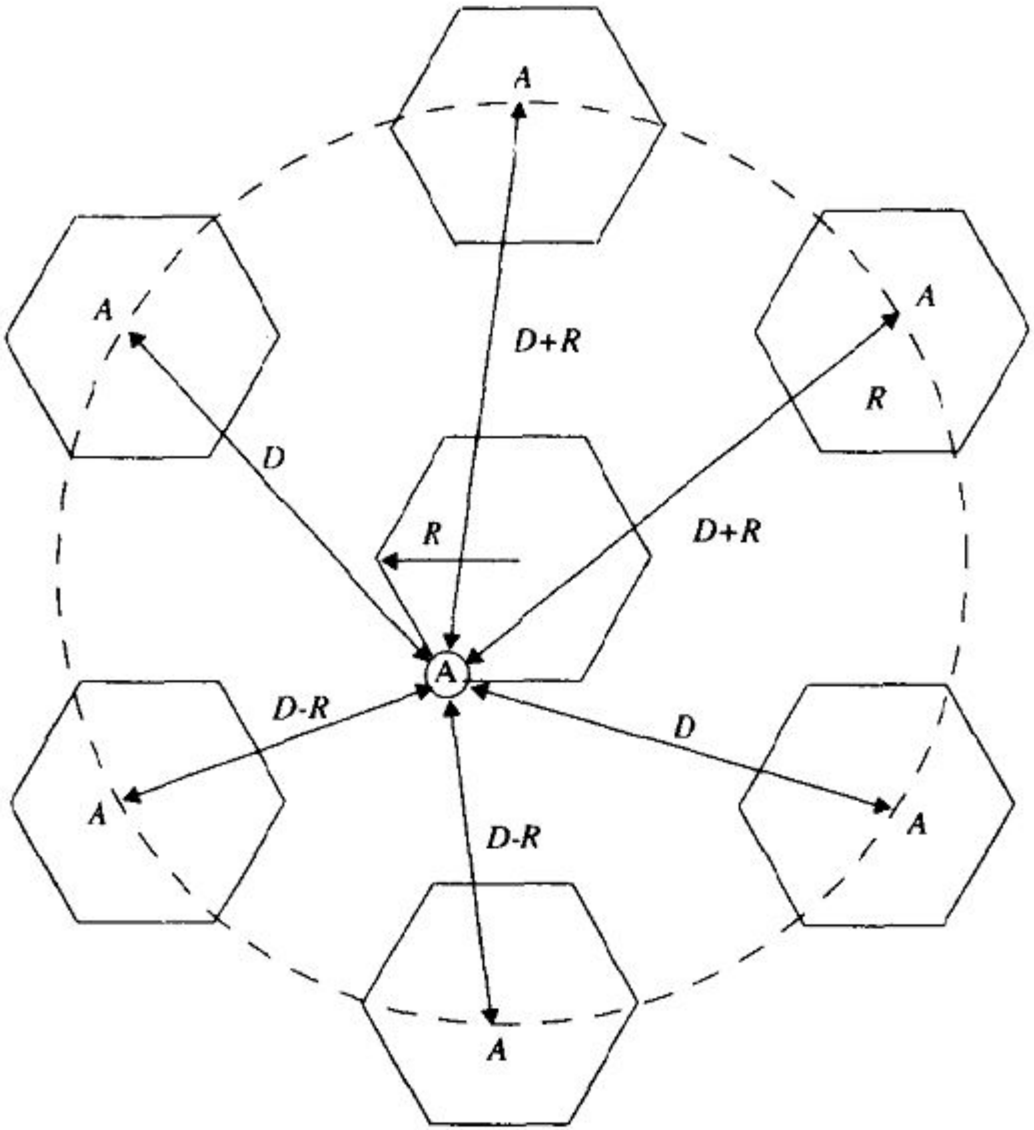
$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

- **There are six co-channels cells in the first tier, so i_0=6**

Illustration of first layer interfering cells

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D+R)^{-4} + 2D^{-4}}$$

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}$$



Example #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.

(a) $n = 4$

First, let us consider a 7-cell reuse pattern.

Using equation (2.4), the co-channel reuse ratio $D/R = 4.583$.

Using equation (2.9), the signal-to-noise interference ratio is given by

$$S/I = (1/6) \times (4.583)^4 = 75.3 = 18.66 \text{ dB}.$$

Since this is greater than the minimum required S/I, $N = 7$ can be used.

Example #2 (cont'd)

b) $n = 3$

First, let us consider a 7-cell reuse pattern.

Using equation (2.9), the signal-to-interference ratio is given by

$$S/I = (1/6) \times (4.583)^3 = 16.04 = 12.05 \text{ dB}.$$

Since this is less than the minimum required S/I, we need to use a larger N.

Using equation (2.3), the next possible value of N is 12, ($i = j = 2$).

The corresponding co-channel ratio is given by equation (2.4) as

$$D/R = 6.0.$$

Using equation (2.3) the signal-to-interference ratio is given by

$$S/I = (1/6) \times (6)^3 = 36 = 15.56 \text{ dB}.$$

Since this is greater than the minimum required S/I, $N = 12$ can be used.

Adjacent Channel Interference

- Channels are allocated such that the frequency separation between channels in a cell is maximized
- By keeping the frequency separation between each channel in a cell as large as possible, the adjacent channel interference may be reduced considerably.

1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147
148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189
190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231
232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252
253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273
274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294

Power Reducing for Reducing Interference

- The goal is to ensure that each mobile transmits the smallest power necessary to maintain a good quality link.
- It will help to prolong the battery life
- It will also dramatically reduce the Signal-to-Interference ratio

Reference

- Wireless Communications: Principles and Practice – Theodore S. Rappaport
  - E-Book, 1st Edition – Section 2.1 – 2.5, Page 25 - 44
  - Paper book, 2nd Edition – Section 3.1 – 3.5, Page 57 - 77