Chapter 3
The Cellular Concept-Fundamentals of design

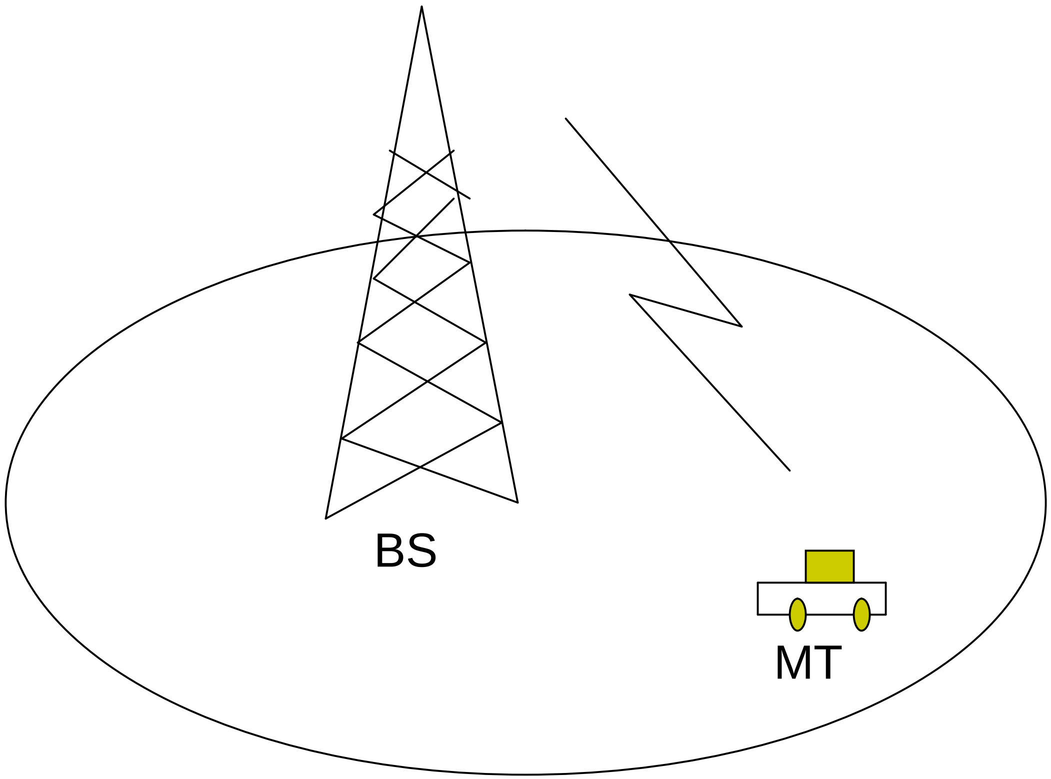
Outline

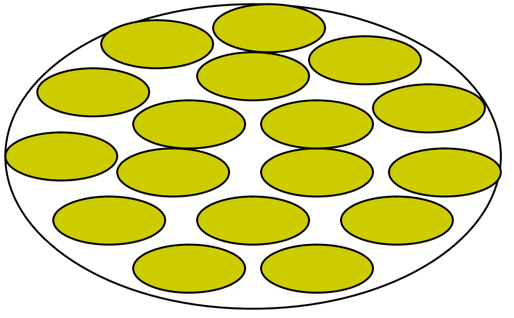
- Introduction
- Frequency Reuse
- Channel Assignment Strategies
- Handoff Strategies
- Interference and System Capacity
- Improving Capacity In Cellular Systems

Introduction

- Early mobile radio systems
  - A single high powered transmitter (single cell)
  - Large coverage area
  - Low frequency resource utility
  - Low user capacity
- The cellular concept
  - A major breakthrough in solving the problem of spectral congestion and user capacity
  - Many low power transmitters (small cells)
  - Each cell covers only a small portion of the service area.
  - Each base station is allocated a portion of the total number of channels
  - Nearby base stations are assigned different groups of channels so that the interference between base stations is minimized

Early mobile radio systems



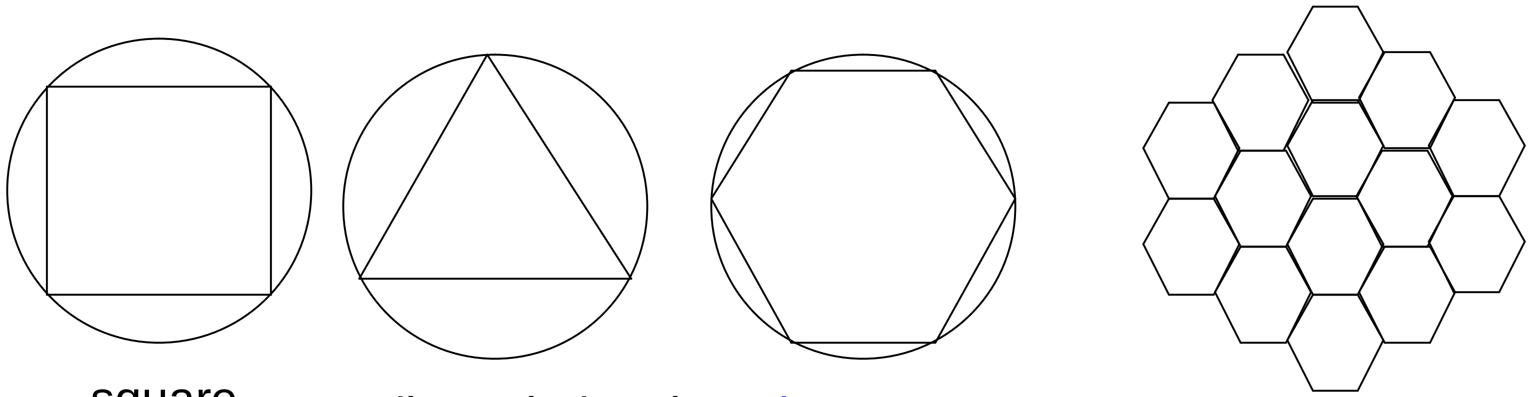


Frequency Reuse

- A service area is split into small geographic areas, called cells.
- Each cellular base station is allocated a group of radio channels.
- Base stations in adjacent cells are assigned different channel groups.
- By limiting the coverage area of a base station, the same group of channels may be reused by different cells far away.
- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning.

Frequency Reuse: Cell Shapes

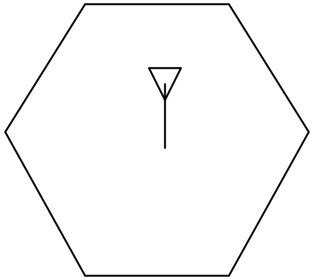
- Geometric shapes covering an entire region without overlap and with equal area.
- By using the hexagon, the fewest number of cells can cover a geographic region, and the hexagon closely approximates a circular radiation pattern which would occur for an omni-directional antenna.

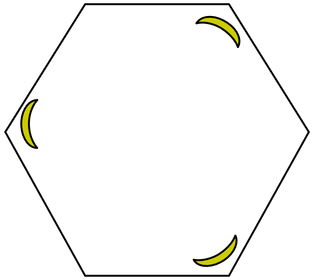


square equilateral triangle hexagon

Frequency Reuse: Excitation modes

- Center-excited cell
  - Base station transmitter is in the center of the cell.
  - Omni-directional antennas are used.
- Edge-excited cell
  - Base station transmitters are on three of the six cell vertices.
  - Sectored directional antennas are used.

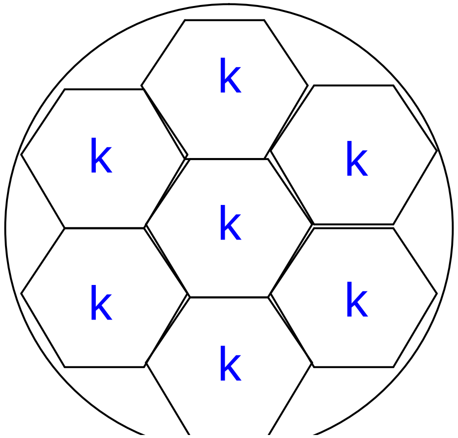




Frequency Reuse: The concept of Cluster

- Consider a cellular system which has a total of S duplex channels available for use.
  - The S channels are divided among N cells (cluster).
  - Each cell is allocated a group of k channels.
  - The total number of available radio channels can be expressed as S=kN.

Cluster: N=7



The N cells which collectively use the complete set of available frequencies is called a cluster.
Cluster size: N=4,7,12
Frequency reuse Factor: 1/N

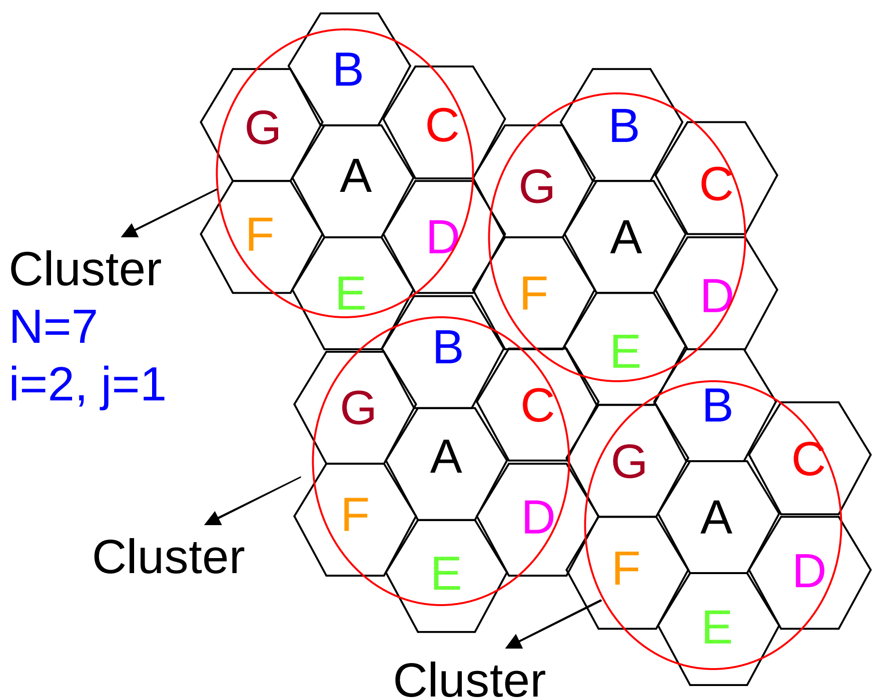
Totally S=kN duplex channels

Frequency Reuse: Reuse Planning

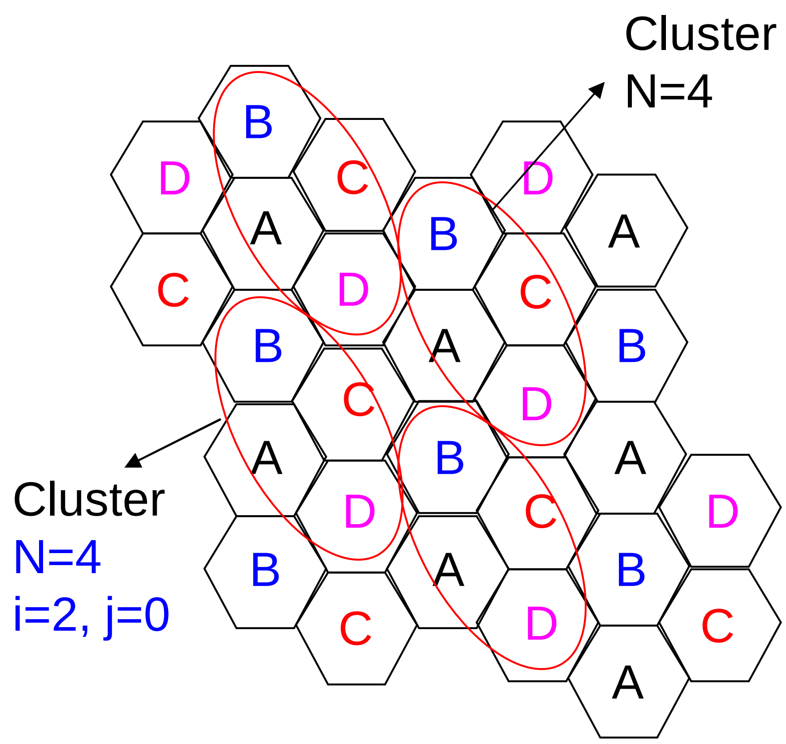
- If a cluster is replicated M times within the system, the total number of duplex channels, C, can be given as $C = MkN = MS$.
- Mathematically, $N = i^2 + ij + j^2$
  - Where i and j are non-negative integers.
  - The nearest co-channel neighbors of a particular cell can be found by doing what follows:
    - move i cells along any chain of hexagons;
    - turn 60 degrees counter-clockwise;
    - move j cells.

Frequency Reuse: Reuse Planning

- Examples



7-cell reuse



4-cell reuse

19-cell reuse example (N=19)

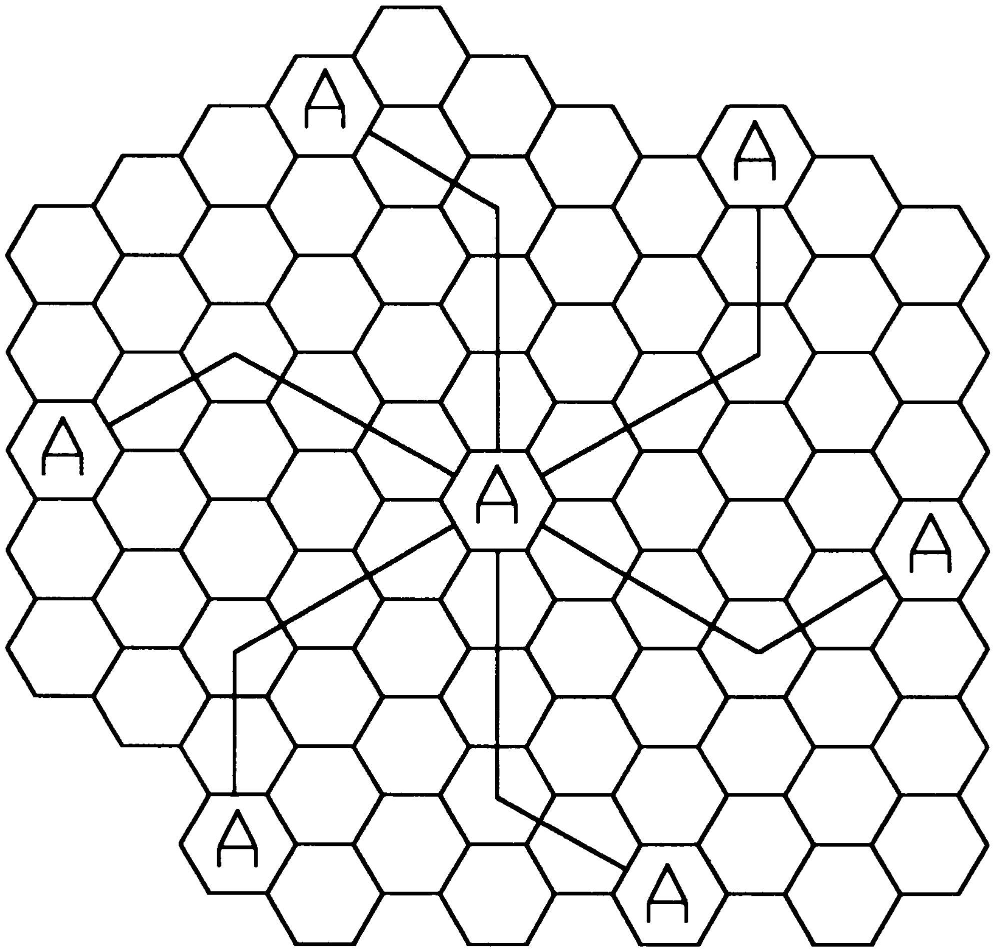


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, $N = 19$ (i.e., $I = 3$, $j = 2$). (Adapted from [Oet83] © IEEE.)

Channel Assignment Strategies

- Objectives:
  - Increasing capacity
  - Minimizing interference
- Classification:
  - Fixed channel assignment strategies
  - Dynamic channel assignment strategies

Fixed channel assignment

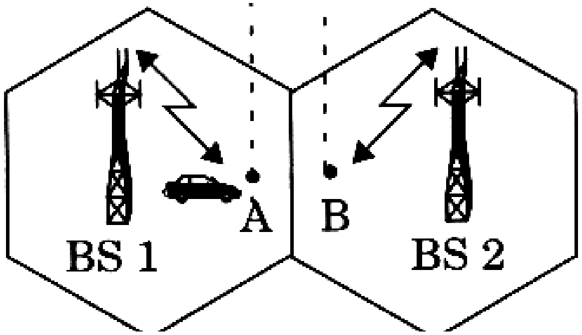
- Each cell is allocated a predetermined set of channels.
- Any call attempt within the cell can only be served by the unused channels in that particular cell.
- If all the channels in that cell are occupied, the call is blocked and the subscriber does not receive service.

Dynamic channel assignment strategies

- Channels are not allocated to different cells permanently.
- Each time a call request is made, the serving base station requests a channel from the MSC.
- The switch then allocates a channel to the requested cell following an algorithm that takes into account:
  - the likelihood of fixture blocking within the cell
  - the frequency of use of the candidate channel
  - the reuse distance of the channel
  - other cost functions.

Handoff Strategies

- Handoff:
  - When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station.
- Processing handoffs is an important task in any cellular radio system.



Handoff Strategies: Requirements

- Handoffs must be performed:
  - Successfully;
  - As infrequently as possible;
  - Imperceptible to the users.
- How to meet these requirements?
  - Specify an optimum signal level to initiate a handoff;
  - Decide optimally when to handoff;
  - Consider the statistics of dwell time.

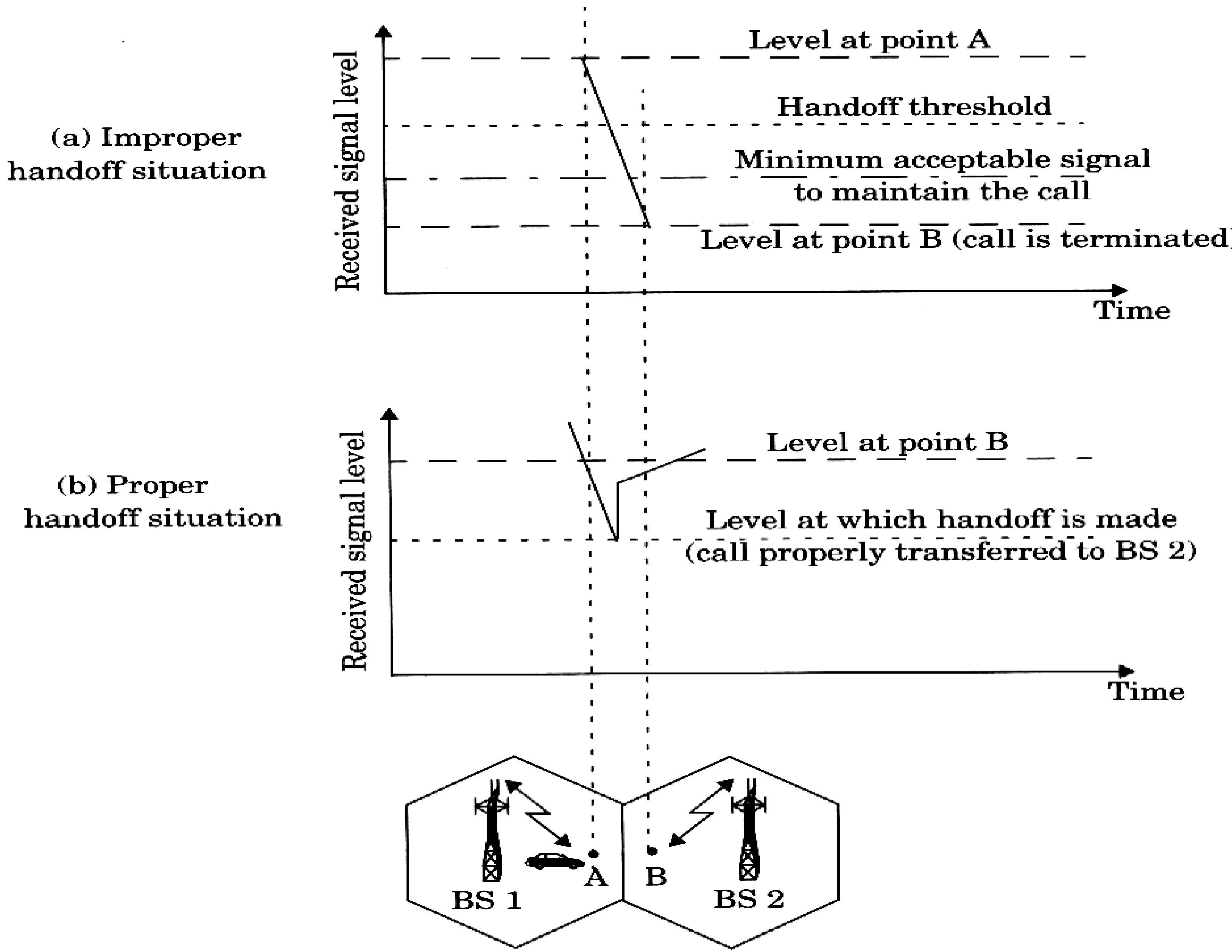


Figure 3.3 Illustration of a handoff scenario at cell boundary.

Handoff Strategies: Signal strength measurements

- First generation analog cellular systems:
  - Signal strength measurements are made by the base stations and supervised by the MSC.
- Second generation systems:
  - Handoff decisions are mobile assisted;
  - The MSC no longer constantly monitors signal strengths.

Handoff Strategies: Managing of handoffs

- Prioritizing Handoffs
  - Guard channel: a fraction of the total available channels in a cell is reserved exclusively for handoff requests from ongoing calls which may be handed off into the cell.
  - Queuing of handoff requests: to decrease the probability of forced termination of a call due to lack of available channels.
    - Queuing of handoffs is possible due to the fact that there is a finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated due to insufficient signal level.

Practical Handoff Considerations

- Observations
  - High speed vehicles pass through the coverage region of a cell within a matter of seconds.
  - Pedestrian users may never need a handoff during a call.
  - Particularly with the addition of microcells to provide capacity, the MSC can quickly become burdened if high speed users are constantly being passed between very small cells.
  - It is difficult for cellular service providers to obtain new physical cell site locations in urban areas.
  - Another practical handoff problem in microcell systems is known as cell dragging.
- Solutions
  - The umbrella cell approach.
  - Newer cellular systems make handoff decisions based on a wide range of metrics other than signal strength.
  - Soft handoff (CDMA cellular networks): The ability to select between the instantaneous received signals from a variety of base stations is called soft handoff.

The umbrella cell approach

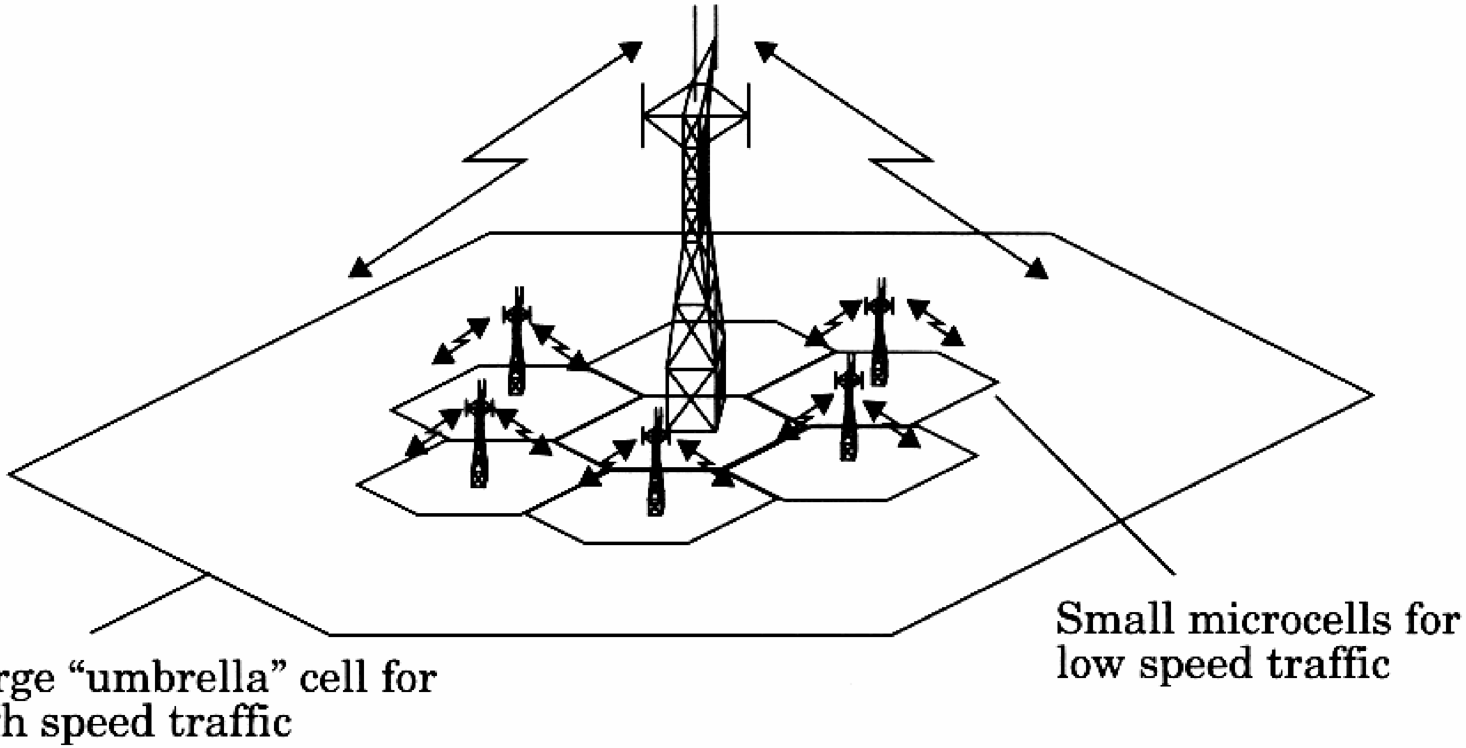


Figure 3.4 The umbrella cell approach.

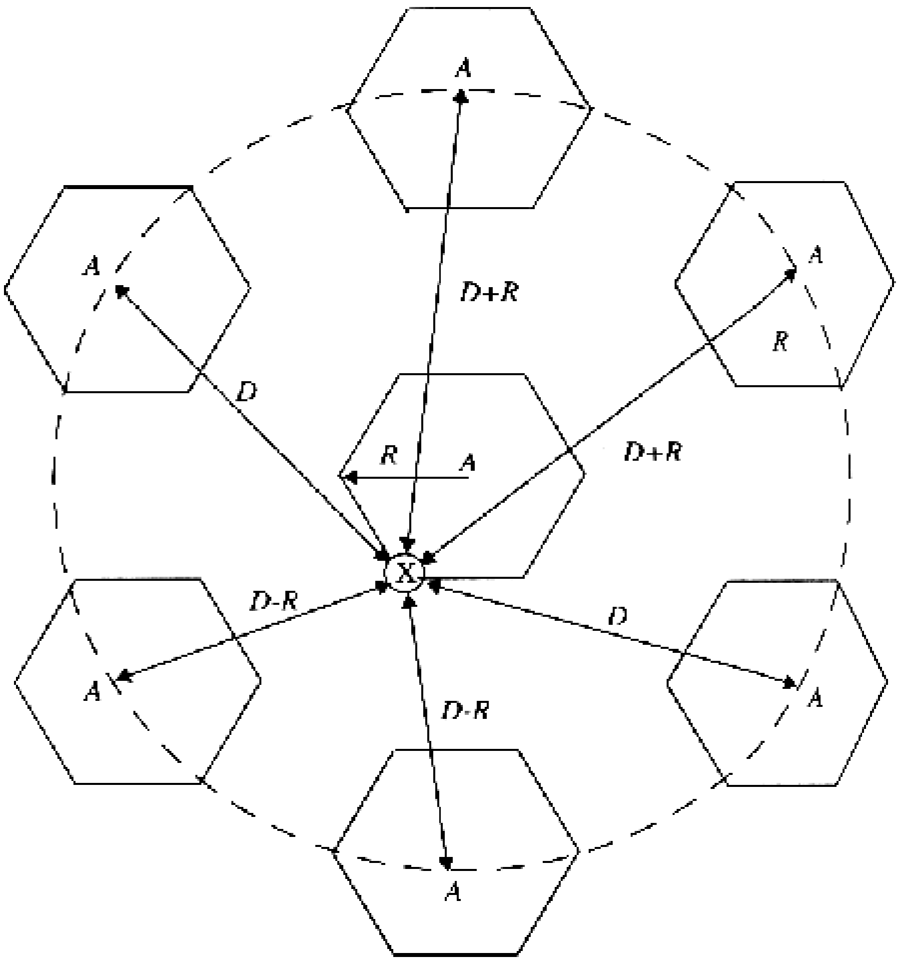
Interference and System Capacity

- Interference is the major limiting factor in the performance of cellular radio systems:
  - a major bottleneck in increasing capacity
  - often responsible for dropped calls
- The two major types of system-generated cellular interference are:
  - co-channel interference
  - adjacent channel interference
- Power Control for Reducing Interference

Co-channel Interference and System Capacity

- **Co-channel Interference**
  - Cells using the same set of frequencies are called co-channel cells, and the interference between signals from these cells is called co-channel interference.
  - Unlike thermal noise which can be overcome by increasing the signal-to-noise ration (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter. This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells.
  - 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 cells for 7-cell reuse



Co-channel Interference and System Capacity

- The co-channel interference ratio is a function of the radius of the cell (B) and the distance between centers of the nearest co-channel cells (D).
- By increasing the ratio of D/R, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased. Thus interference is reduced.

Cochannel reuse ratio

- The parameter $Q = D/R$, called the cochannel reuse ratio, is related to the cluster size N.
  - When the size of each cell is approximately the same, and the base stations transmit the same power, we have

$$Q = D/R = (3N)^{1/3}$$

  - A small value of Q provides larger capacity since the cluster size N is small, whereas a large value of Q improves the transmission quality, due to a smaller level of co-channel interference.
  - A trade-off must be made between these two objectives in actual cellular design.

Smaller N is greater capacity

Table 3.1 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

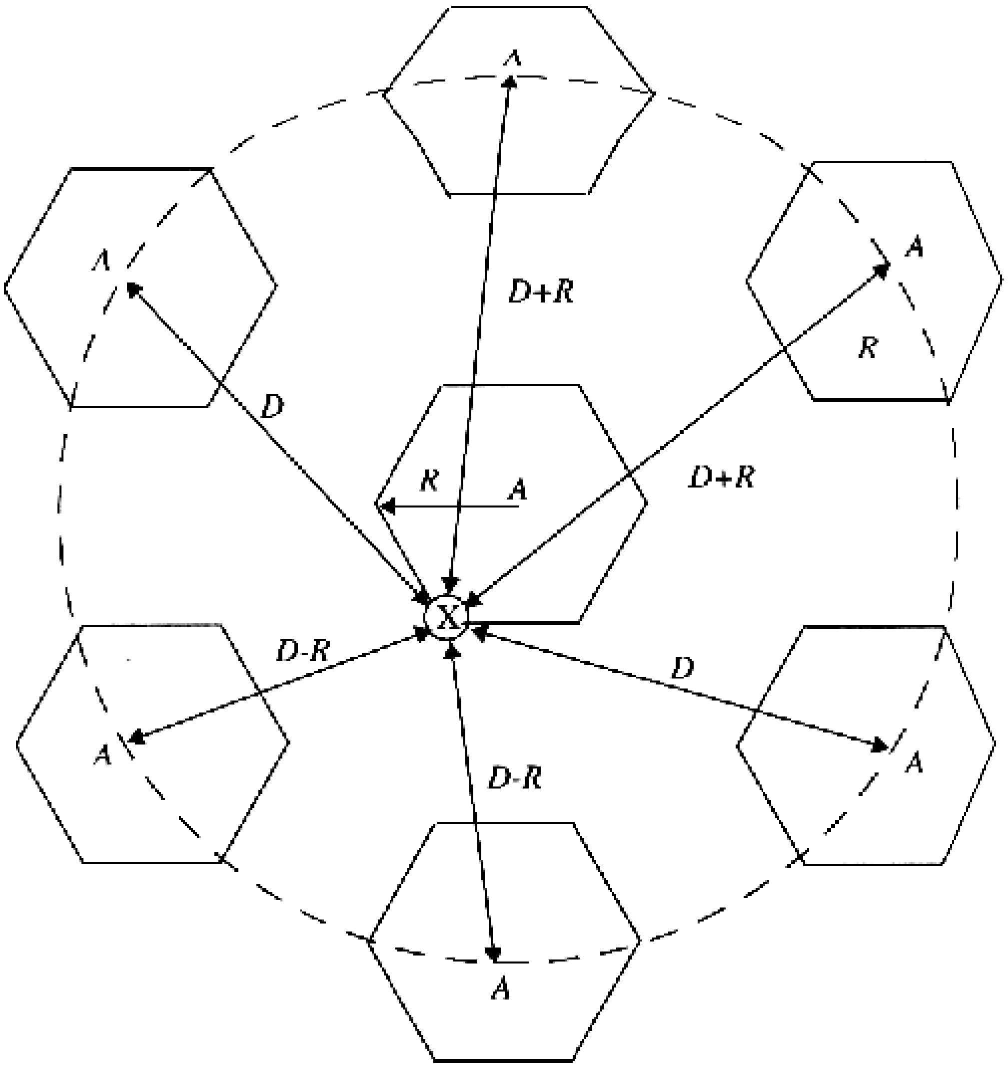
Signal-to-interference ratio (SIR)

- The signal-to-interference ratio (SIR) for a mobile receiver can be expressed as

$$SIR = \frac{S}{\sum_{i=0}^{i_0} I_i}$$

  - S denotes the desired signal power;
  - I_i is the interference power caused by the i-th interfering co-channel cell base station;
  - i_0 is the number of cochannel interfering cells.

Signal-to-interference ratio (SIR)



Signal-to-interference ratio (SIR)

- The average received power P at a distance *d* from the transmitting antenna is approximated by

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

- If all base stations transmit at the same power level, the SIR can be given as

$$SIR = \frac{R^{-n}}{\sum_{i=0}^{i_0} D_i^{-n}}$$

- In practice, measures should be taken to keep the SIR on a acceptable level.

Adjacent Channel Interference

- Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.
- Near-far effect:
  - If an adjacent channel user is transmitting in very close range to a subscriber's receiver, the problem can be particularly serious.

Adjacent Channel Interference

- Adjacent channel interference can be minimized through careful filtering and channel assignments:
  - By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference may be reduced considerably.
  - Channel allocation schemes can also prevent a secondary source of adjacent channel interference by avoiding the use of adjacent channels in neighboring cell sites.
  - High Q cavity filters can be used in order to reject adjacent channel interference.

Table 3.2 AMPS Channel Allocation for A and B Side Carriers

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	20	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
295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	-	-	-
313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	667	668	669
670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690
691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711
712	713	714	715	716	-	-	-	-	991	992	993	994	995	996	997	998	999	1000	1001	1002

A SIDE

Power Control for Reducing Interference

- In practical cellular radio and personal communication systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations.
- This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel.
- Power control not only helps prolong battery life for the subscriber unit, but also dramatically improves the reverse channel S/I in the system.
- Power control is especially important for emerging CDMA spread spectrum systems that allow every user in every cell to share the same radio channel.

Improving Capacity In Cellular Systems

- As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users.
- Techniques to expand the capacity of cellular systems :
  - Cell splitting: increases the number of base stations in order to increase capacity.
  - Sectoring: relies on base station antenna placements to improve capacity by reducing co-channel interference.
  - Coverage zone: distributes the coverage of a cell and extends the cell boundary to hard-to-reach places.

Cell Splitting

- Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power.
- Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused.

Cells are split to add channels with no new spectrum usage

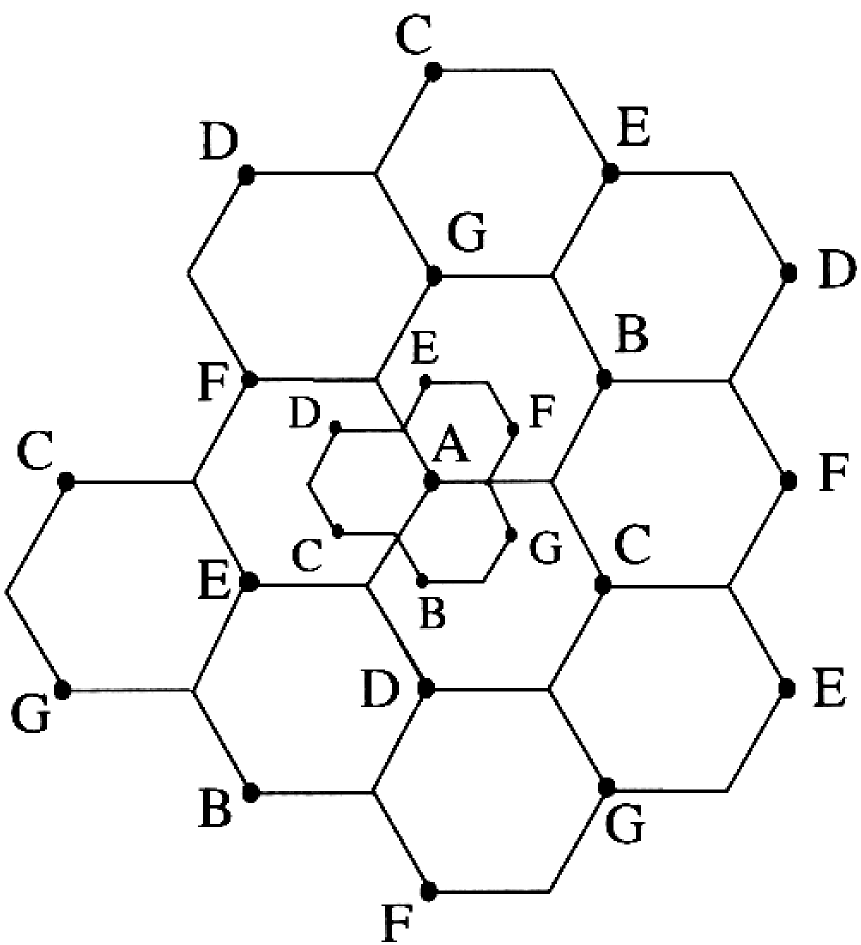


Figure 3.8 Illustration of cell splitting.

Cell Splitting increases capacity

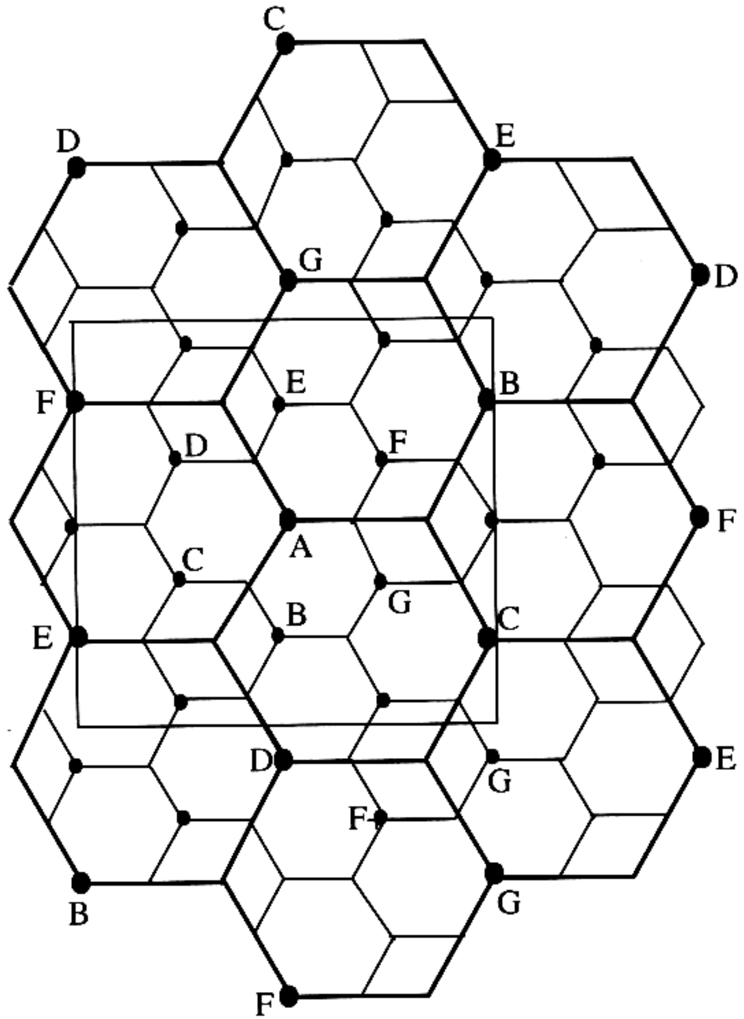


Figure 3.9 Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

Sectoring

- The technique for decreasing co-channel interference and thus increasing system capacity by using directional antennas is called sectoring.
- The factor by which the co-channel interference is reduced depends on the amount of sectoring used.

Sectoring improves S/I

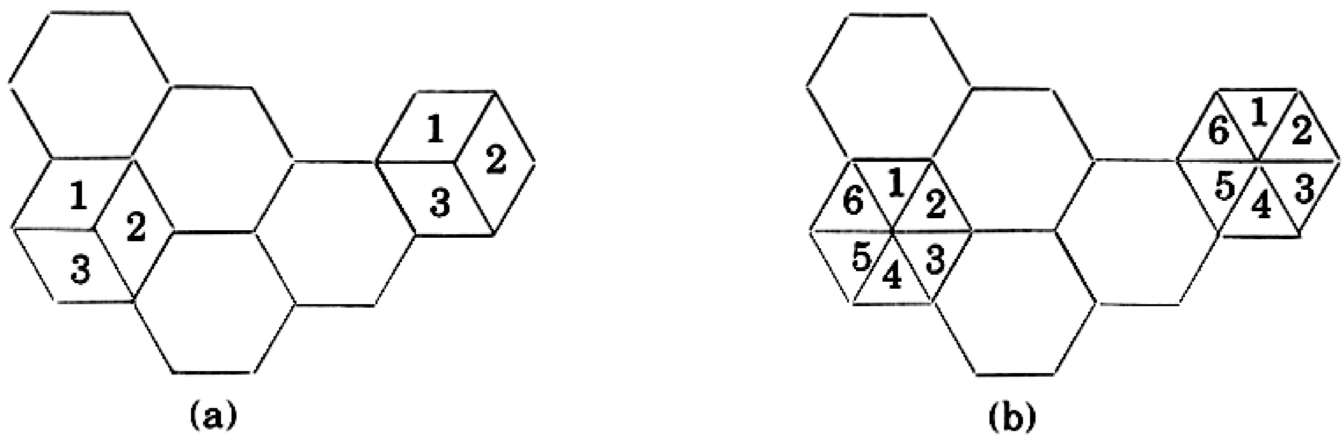


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Sectoring improves S/I

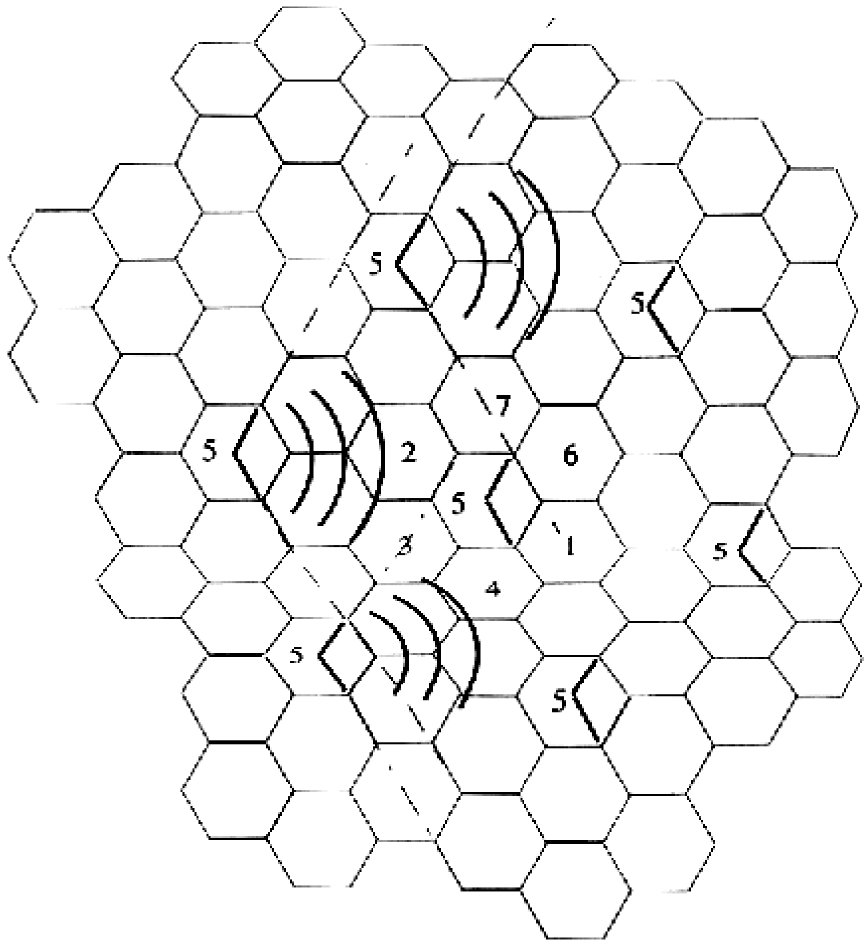


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

A Novel Microcell Zone Concept

- Zone Concept
  - Zone sites are connected to a single base station and share the same radio equipment.
  - The zones are connected by coaxial cable, fiberoptic cable, or microwave link to the base station.
  - Multiple zones and a single base station make up a cell.
  - As a mobile travels within the cell, it is served by the zone with the strongest signal.
  - This technique is particularly useful along highways or along urban traffic corridors.
- This approach is superior to sectoring since antennas are placed at the outer edges of the cell, and any base station channel may be assigned to any zone by the base station.
- In comparison with sectoring, the number of handoffs can be reduced significantly.

The Zone Cell Concept

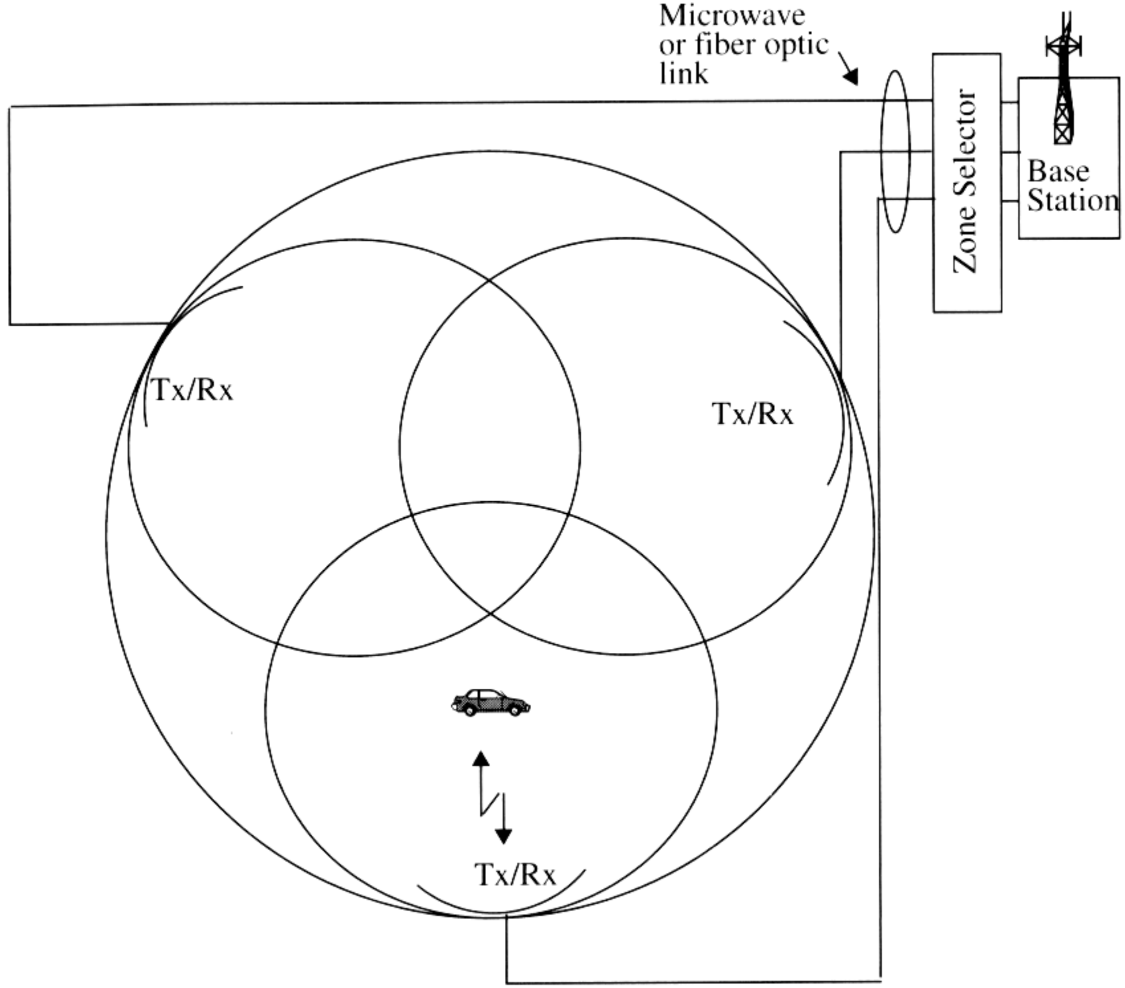


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].