Wireless Communications

Principles and Practice

2nd Edition

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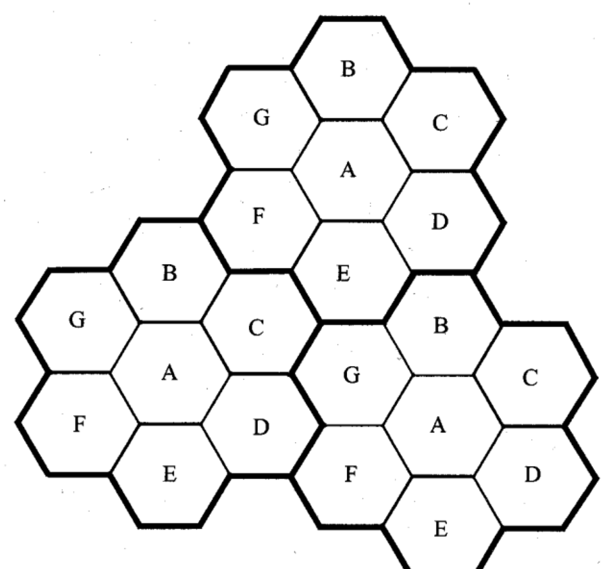
Chapter 3: The Cellular Concept – System Design Fundamentals

The Cellular Concept

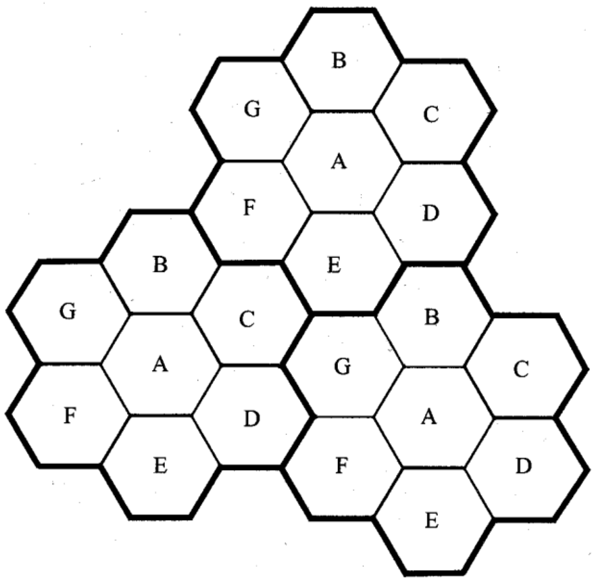
- A geographic area is divided into a number of small areas (cells), each cell is allocated a subset of the available frequencies (channels).
- Reuse of radio channels in different cells separated by a sufficient distance to minimize interference.
- Offer very high capacity in a limited spectrum without major technological changes.
- A finite number of channels can serve an arbitrarily large number of users by reusing the channel throughout the coverage region.



Frequency Reuse

- Each cellular base station is allocated a group of radio channels within a small geographic area called a *cell*.
- Neighboring cells are assigned different channel groups.
- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.
- Keep interference levels within tolerable limits.

  - seven groups of channel from A to G



19-cell reuse example (N=19)

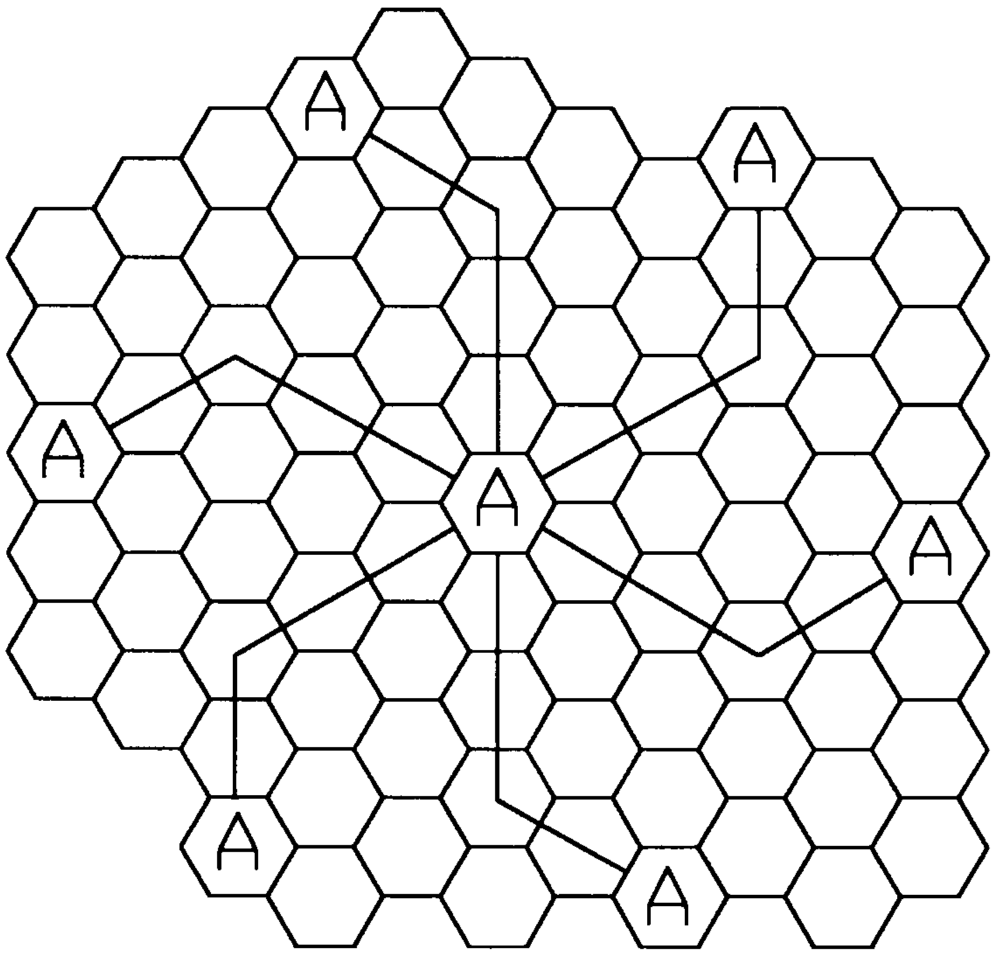


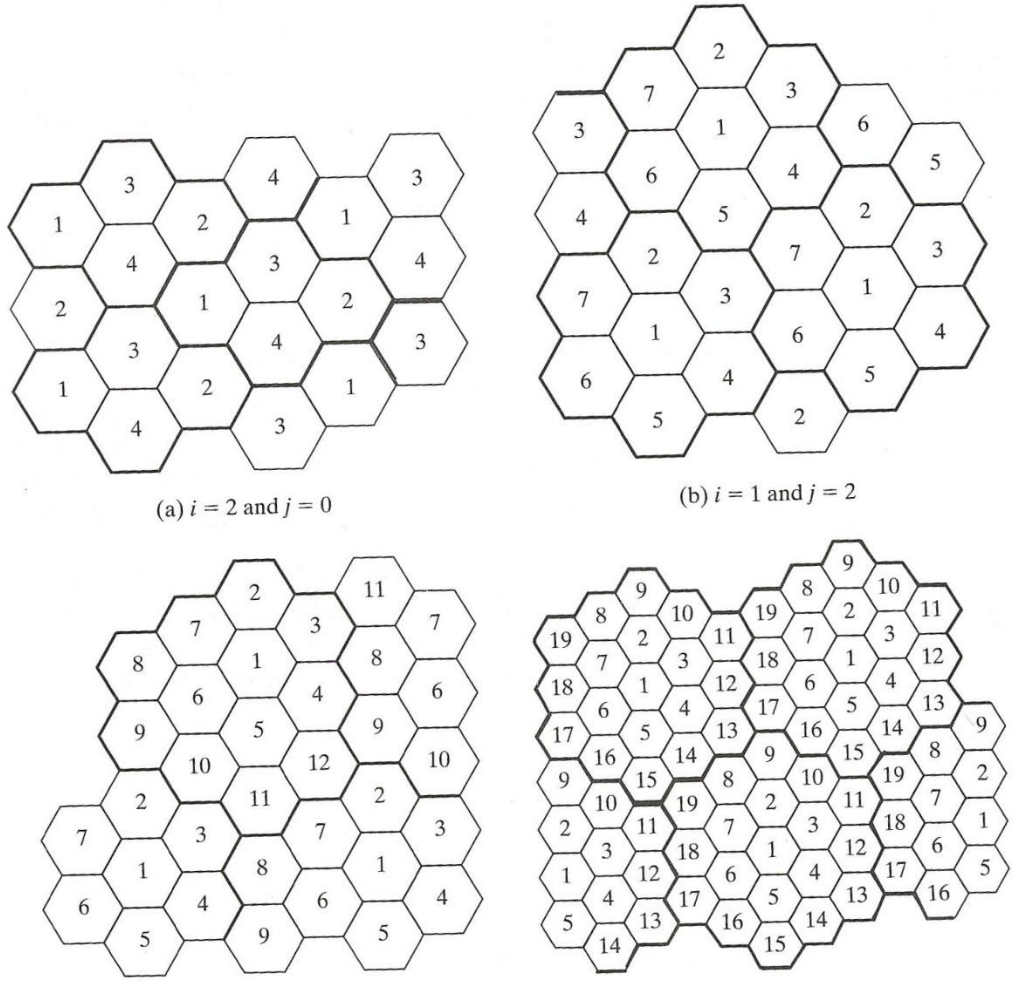
Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, *N* = 19 (i.e., *I* = 3, *j* = 2). (Adapted from [Oet83] © IEEE.)

Frequency Reuse Ratio and Cluster Size

Table 5.1 Frequency Reuse Ratio and Cluster Size

Frequency Reuse Pattern (i, j)	Cluster Size N	Frequency Reuse Ratio q
(1, 1)	3	3.00
(2, 0)	4	3.46
(2, 1)	7	4.58
(3, 0)	9	5.20
(2, 2)	12	6.00
(3, 1)	13	6.24
(3, 2)	19	7.55
(4, 1)	21	7.94
(3, 3)	27	9.00
(4, 2)	28	9.17
(4, 3)	37	10.54

Cell Clusters



(a) $i = 2$ and $j = 0$

(b) $i = 1$ and $j = 2$

(c) $i = 2$ and $j = 2$

(d) $i = 2$ and $j = 3$

Figure 5.2 Cell clusters.

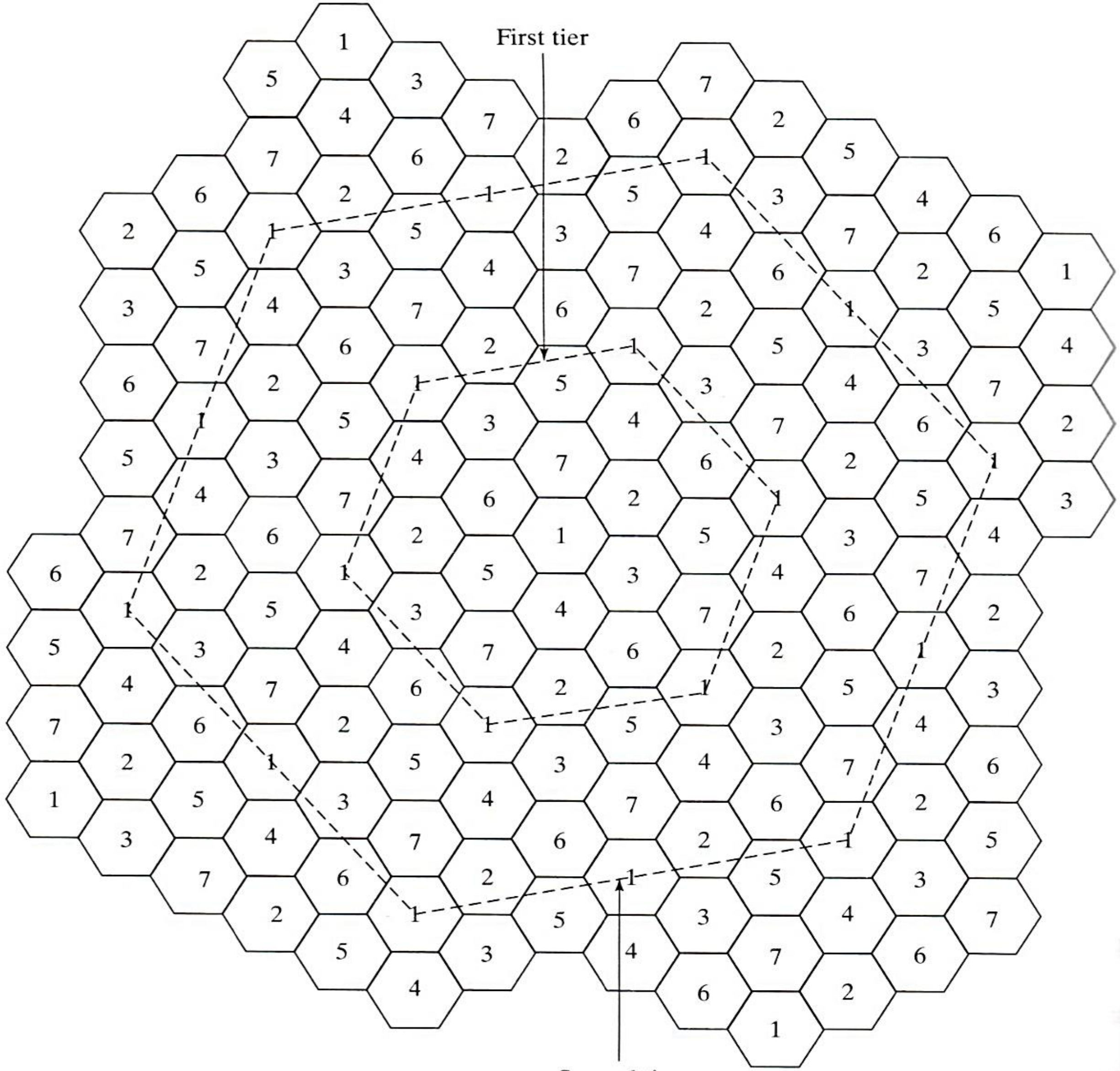


Figure 5.4 Two tiered interfering cells with $N = 7$.

Channel Assignment Strategies

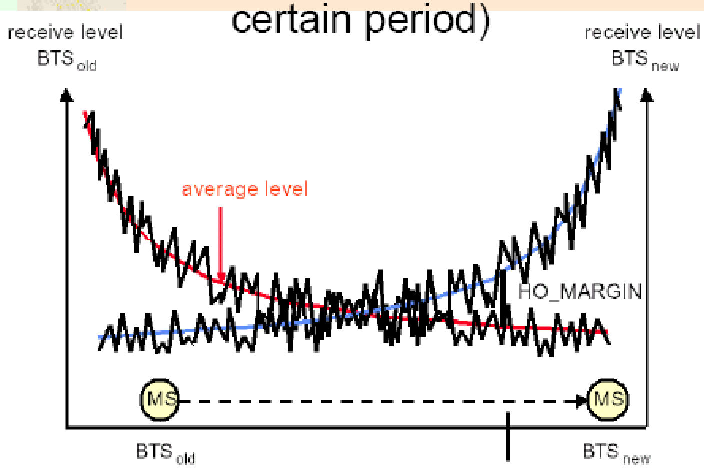
- Frequency reuse scheme
  - increases capacity
  - minimize interference
- Channel assignment strategy
  - fixed channel assignment
  - dynamic channel assignment
- Fixed channel assignment
  - each cell is allocated a predetermined set of voice channel
  - any new call attempt can only be served by the unused channels
  - the call will be *blocked* if all channels in that cell are occupied
- Dynamic channel assignment
  - channels are not allocated to cells permanently.
  - allocate channels based on request.
  - reduce the likelihood of blocking, increase capacity.

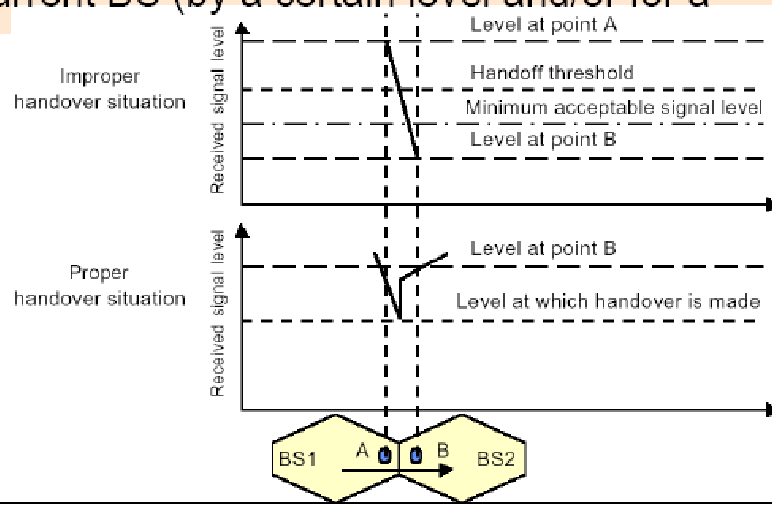
Handoff Strategies

- 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.
- Handoff operation
  - identifying a new base station
  - re-allocating the voice and control channels with the new base station.
- Handoff Threshold
  - Minimum usable signal for acceptable voice quality (-90dBm to -100dBm)
  - Handoff margin $\Delta = P_{r,handoff} - P_{r,\text{minimum usable}}$ cannot be too large or too small.
  - If Δ is too large, unnecessary handoffs burden the MSC
  - If Δ is too small, there may be insufficient time to complete handoff before a call is lost.

HANDOVER

- 1st generation systems (analog cellular):
  - – RSS measurements made by the BSs and supervised by the MSC
  - – the BS constantly monitors RSS of all the voice channels
  - – *locator receiver* measures RSS of MSs in neighboring cells
  - – MSC decides if a handover is necessary or not
- 2nd generation systems (digital TDMA):
  - – handover decisions are *mobile assisted* - MAHO
  - – every MS measures the RSS from surrounding BSs and sends *reports* to its own BS
  - – handover is initiated when RSS received from a neighbor BS begins to exceed RSS from the current BS (by a certain level and/or for a certain period)





- Handoff must ensure that the drop in the measured signal is not due to momentary fading and that the mobile is actually moving away from the serving base station.
- Running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided.
  - Depends on the speed at which the vehicle is moving.
  - The speed can be estimated from the statistics of the received short-term fading signal at the base station

Practical Handoff Consideration

- Different type of users
  - High speed users need frequent handoff during a call.
  - Low speed users may never need a handoff during a call.
- Microcells to provide capacity, the MSC can become burdened if high speed users are constantly being passed between very small cells.
- Minimize handoff intervention
  - handle the simultaneous traffic of high speed and low speed users.
- Large and small cells can be located at a single location (umbrella cell)
  - different antenna height
  - different power level
- Cell dragging problem: pedestrian users provide a very strong signal to the base station
  - The user may travel deep within a neighboring cell

Umbrella Cells

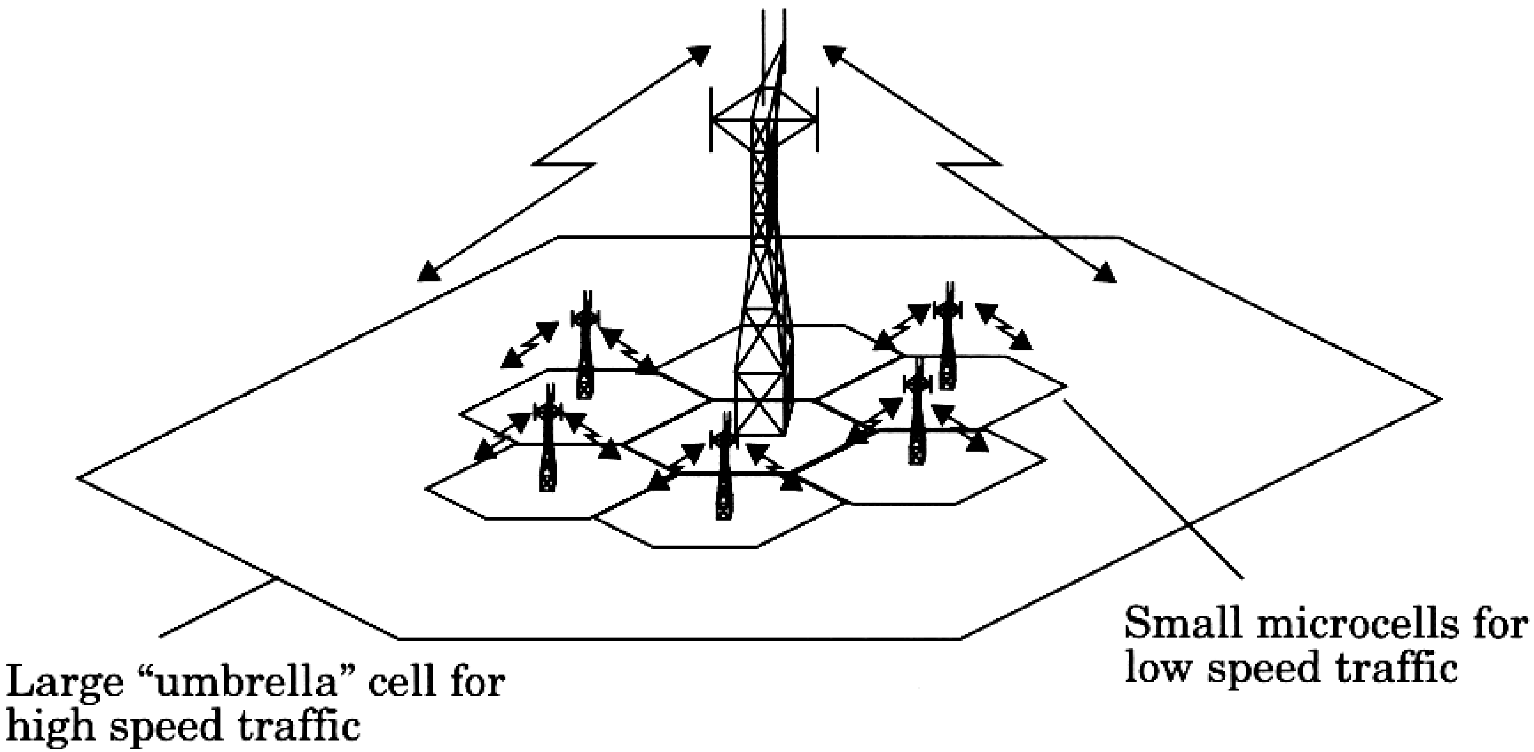
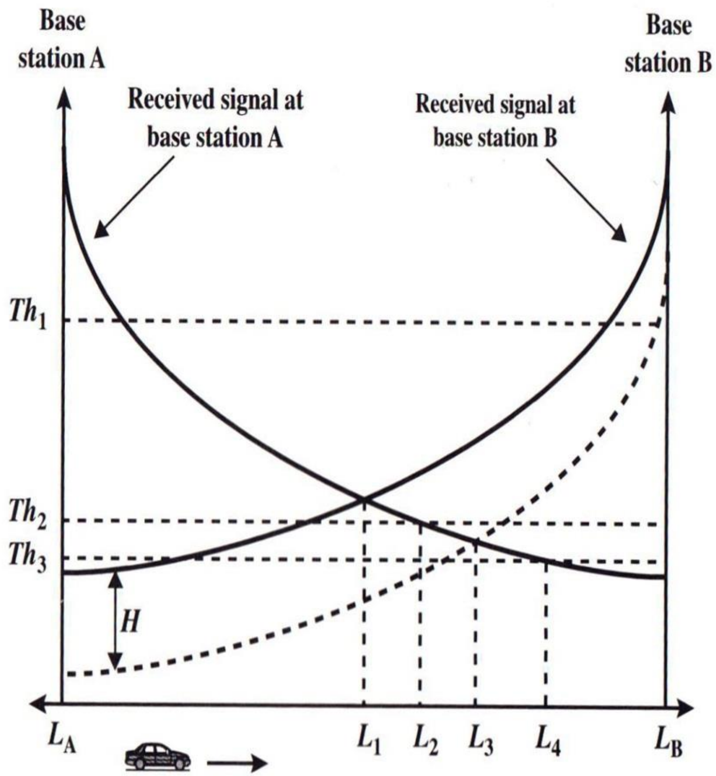


Figure 3.4 The umbrella cell approach.

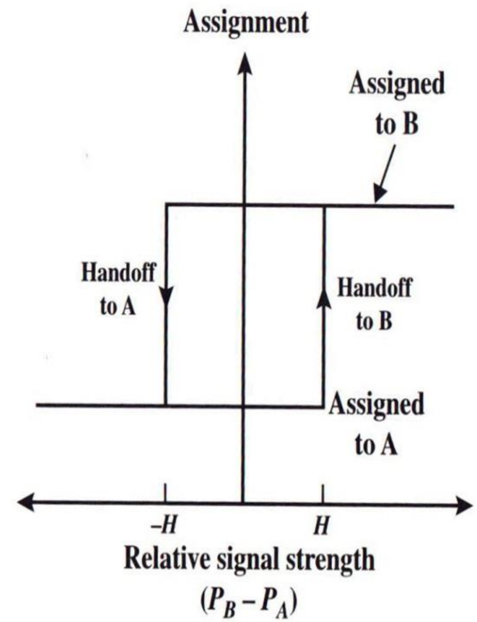
- Handoff for first generation analog cellular systems
  - 10 secs handoff time
  - Δ is in the order of 6 dB to 12 dB
- Handoff for second generation cellular systems, e.g., GSM
  - 1 to 2 seconds handoff time
  - mobile assists handoff
  - Δ is in the order of 0 dB to 6 dB
  - Handoff decisions based on signal strength, co-channel interference, and adjacent channel interference.
- IS-95 CDMA spread spectrum cellular system
  - Mobiles share the channel in every cell.
  - No physical change of channel during handoff
  - MSC decides the base station with the best receiving signal as the service station
-

HANDOVER

- **Network Controlled HO (NCHO)**
  - The network makes the decision
    - BS monitors the signal strength and quality from the MS
    - Network uses multiple (current and surrounding) BSs to supervise the quality of all current connections by making measurements of RSS
    - MSC makes the decision when and where to effect the handoff
    - Heavy network signaling traffic and limited radio resources at BSs prevent frequent measurements of neighboring links ⇒ long HO times
  - HO times : up to 10s or more
- **Mobile Assisted HO (MAHO)**
  - the mobile provides data which the network uses to make the decision
  - essentially it is a variant of NCHO
  - HO times can be reduced (about 1s in GSM)
- **Mobile Controlled HO (MCHO)**
  - MS decides for itself by monitoring signal strength and quality from the current and candidate base stations; when it finds a "better" candidate it initiates a handoff



(a) Handoff decision as a function of handoff scheme



(b) Hysteresis mechanism

Figure 10.7 Handoff between Two Cells

Methods to determine the instant of handoff

- <u>Relative Signal Strength</u>: The mobile unit is handed off from BS (A) to BS(B) when the signal strength at (B) first exceeds that of (A).
  - Hand off occurs at point L1
  - Disadvantage is the ping-pong effect (repeated handoff A-B).

- <u>Relative signal strength with threshold:</u> Handoff only occurs if

1) Signal at the current BS is sufficiently weak (less than a given threshold), 2) The 2nd BS has a stronger signal.

The idea is that as long as the signal of the current BS is sufficient, handoff is unnecessary.

If threshold is high (Th1) this method performs as the previous one (i.e. at L1). With threshold (Th2) handoff occurs at (L2). With threshold (Th3) handoff occurs at (L4) which is far into the new cell.

- Relative signal strength with hysteresis: Handoff occurs only if the new BS is sufficiently stronger (by a margin of H) than the current one.

  Handoff occurs at L3. This method prevents the ping-pong effect.
  - Disadvantage: The handoff may be unnecessary and BS(A) may still has sufficient signal strength.

- Relative signal stremgth with hysteresis and threshold: Handoff occurs only if: 1) the current signal level drops below a threshold
- 2) BS(B) is stronger than BS(A) by a margin (H).
  - Th1 and Th2 result in handoff at L3.
  - Th3 result in handoff at L4.

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

Co-channel cells for 7-cell reuse

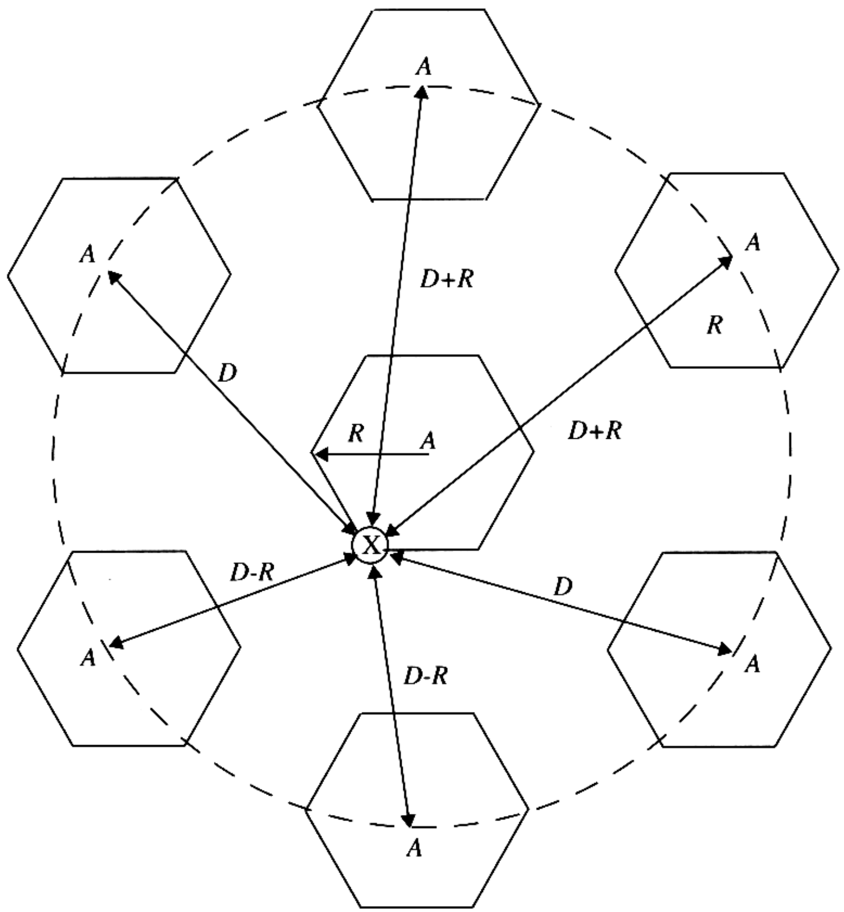


Figure 3.5 Illustration of the first tier of co-channel cells for a cluster size of $N = 7$. An approximation of the exact geometry is shown here, whereas the exact geometry is given in [Lee86]. When the mobile is at the cell boundary (point X), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

AMPS Duopoly Channels

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	A
211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	SIDE
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	
1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	
334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	
355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	
376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	
397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	
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460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	
481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	
502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	
523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	B
544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	SIDE
565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	
607	608	609	610	611	6612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	
628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	
649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	-	-	-	
-	-	-	-	-	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	
733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	
754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	
775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	
796	797	798	799																		

Key Definitions for Trunked Radio

Table 3.3 Definitions of Common Terms Used in Trunking Theory

Set-up Time: The time required to allocate a trunked radio channel to a requesting user.

Blocked Call: Call which cannot be completed at time of request, due to congestion. Also referred to as a *lost call*.

Holding Time: Average duration of a typical call. Denoted by H (in seconds).

Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs. This is a dimensionless quantity and may be used to measure the time utilization of single or multiple channels. Denoted by A.

Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.

Grade of Service (GOS): A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).

Request Rate: The average number of call requests per unit time. Denoted by λ seconds^{-1}.

Erlang B Trunking GOS

Table 3.4 Capacity of an Erlang B System

Number of Channels *C*	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
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
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

Erlang B

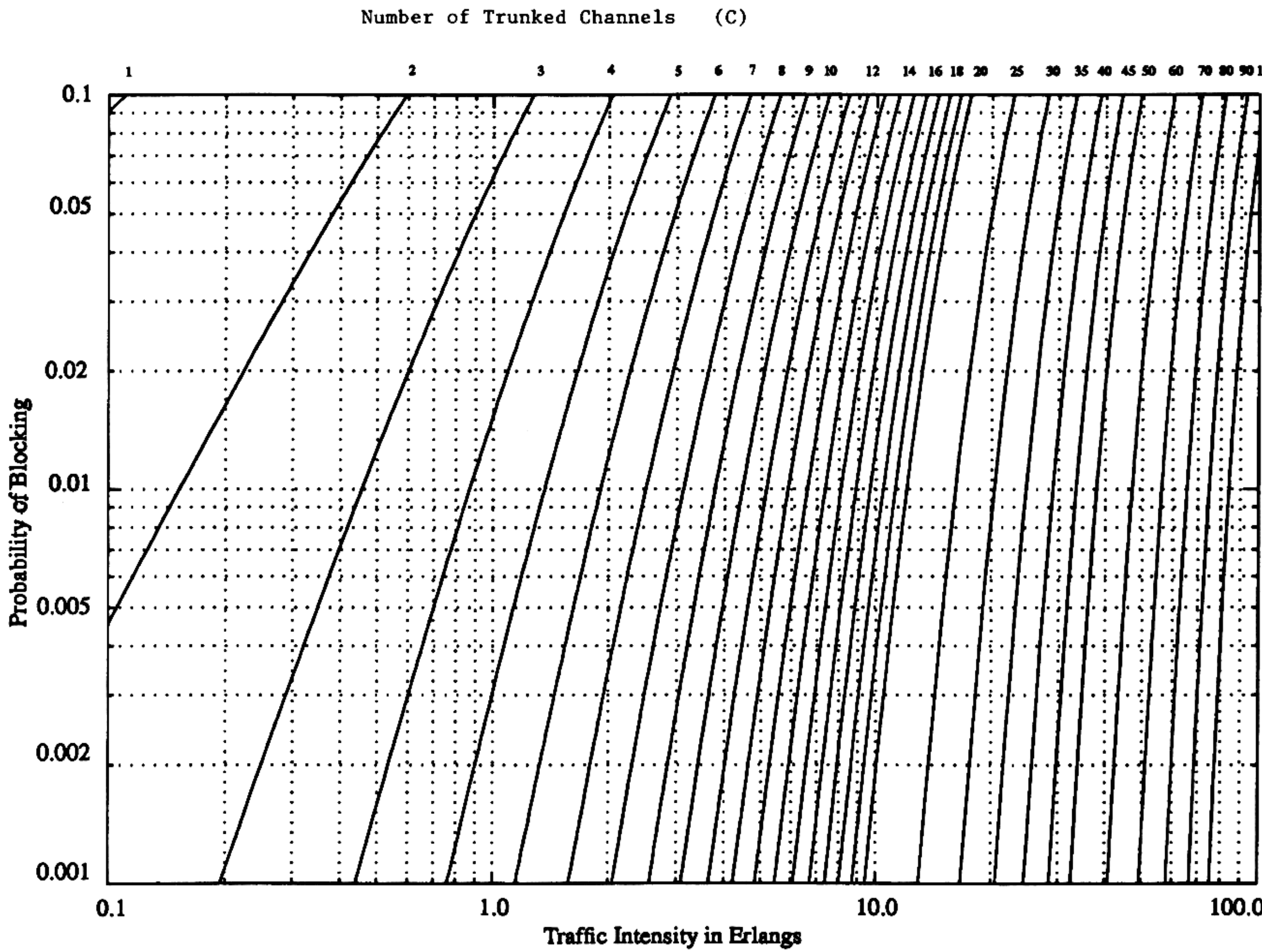


Figure 3.6 The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

Erlang C

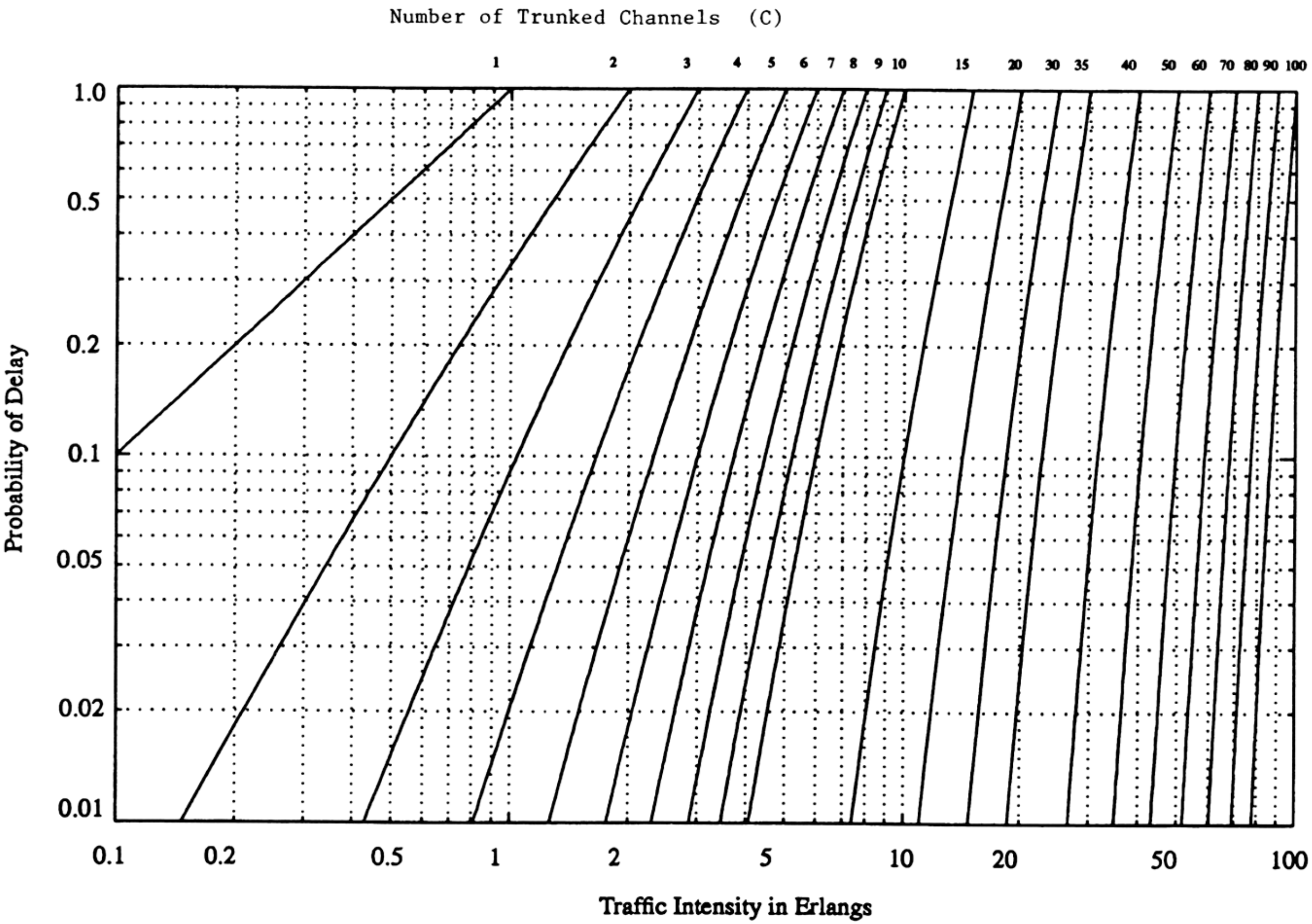


Figure 3.7 The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Cells are split to add channels with no new spectrum usage

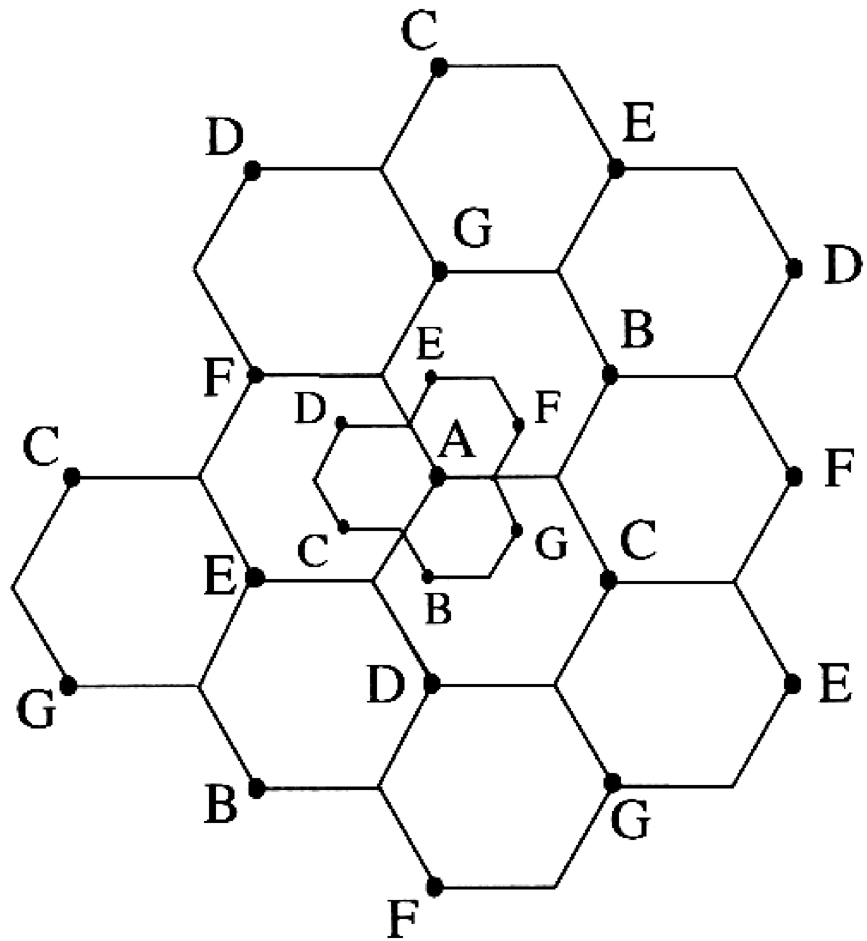


Figure 3.8 Illustration of cell splitting.

Cell Splitting increases capacity

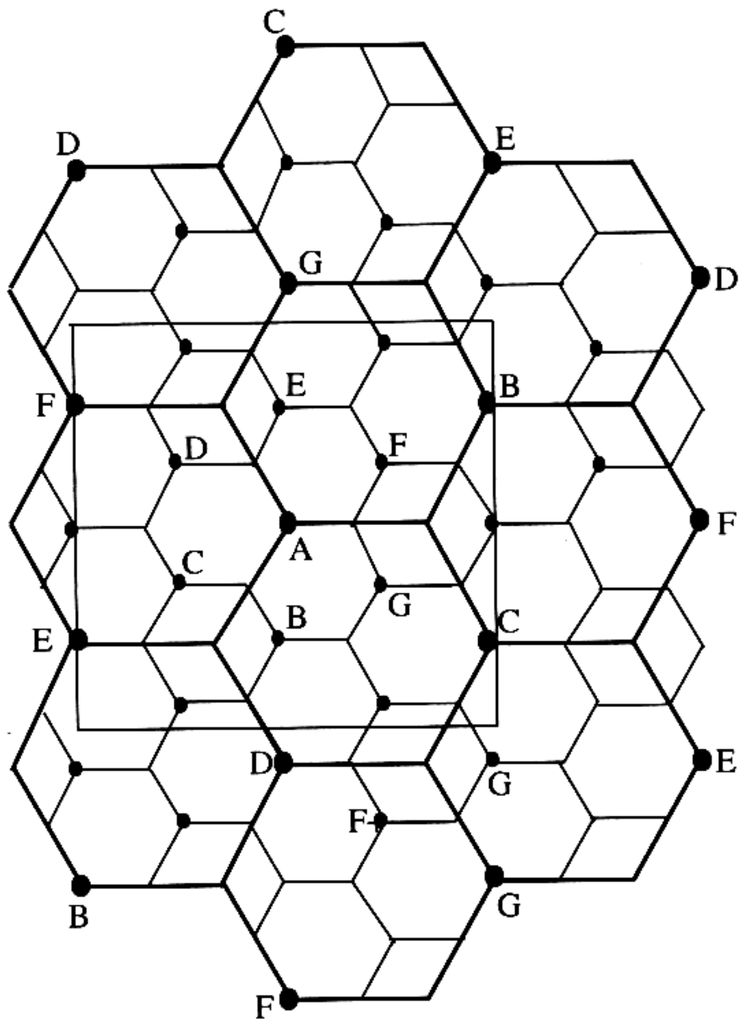
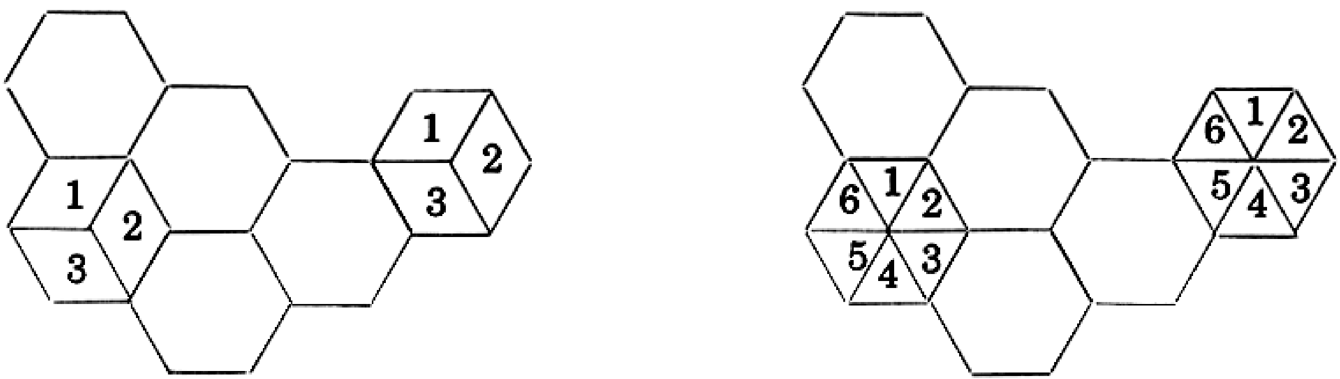


Figure 3.9 Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

Sectoring improves S/I



(a)

(b)

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

Sectoring improves S/I

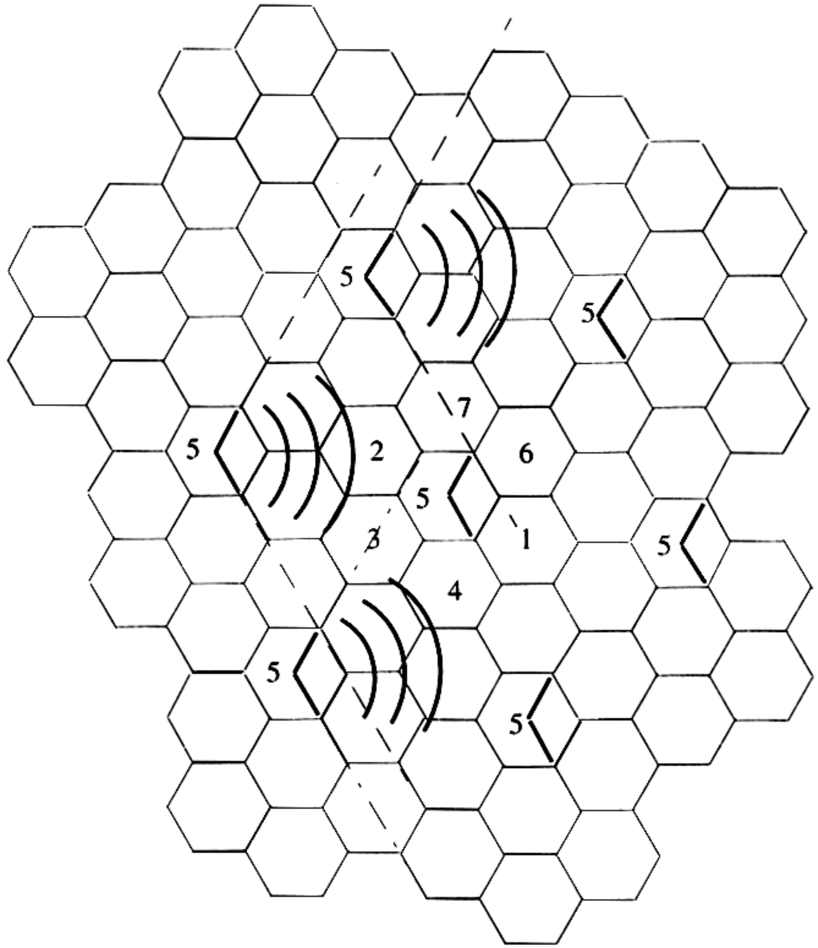


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center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

In-building deployment is the next great growth phase

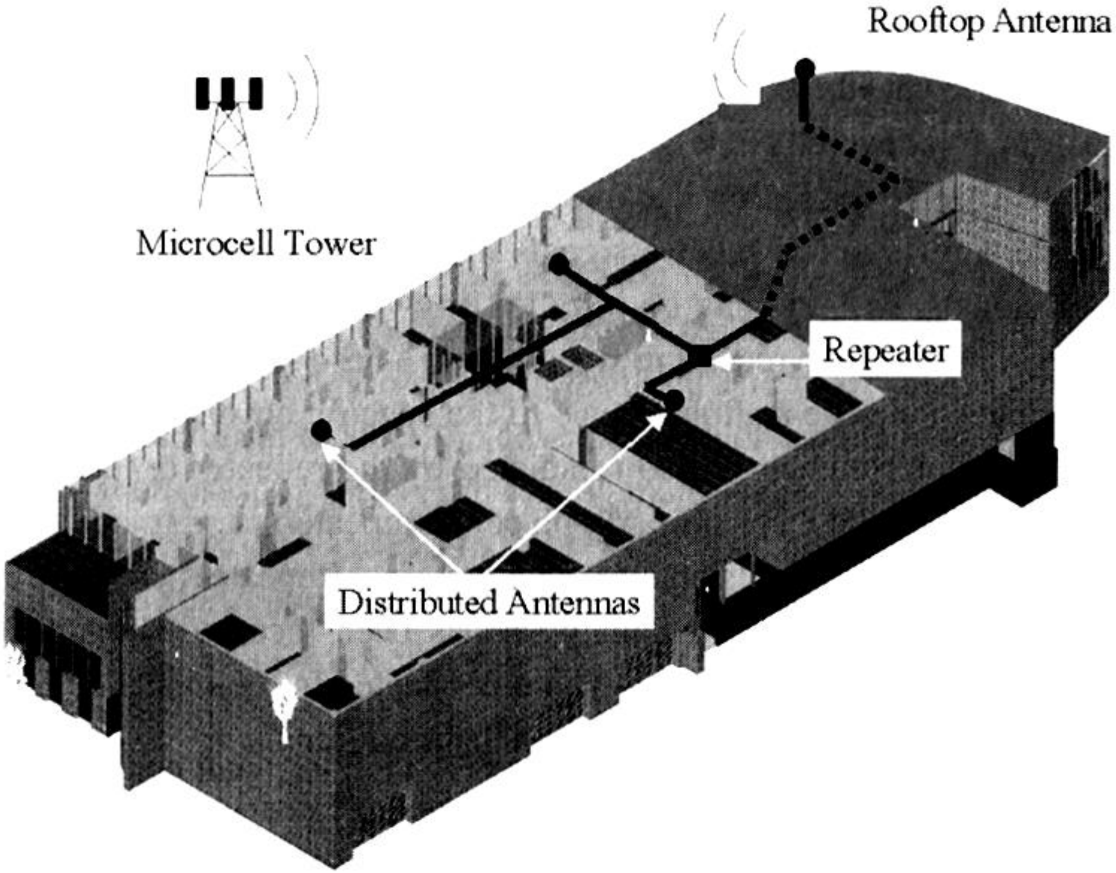


Figure 3.12 Illustration of how a distributed antenna system (DAS) may be used inside a building. Figure produced in SitePlanner®. (Courtesy of Wireless Valley Communications Inc.)

The Zone Cell Concept

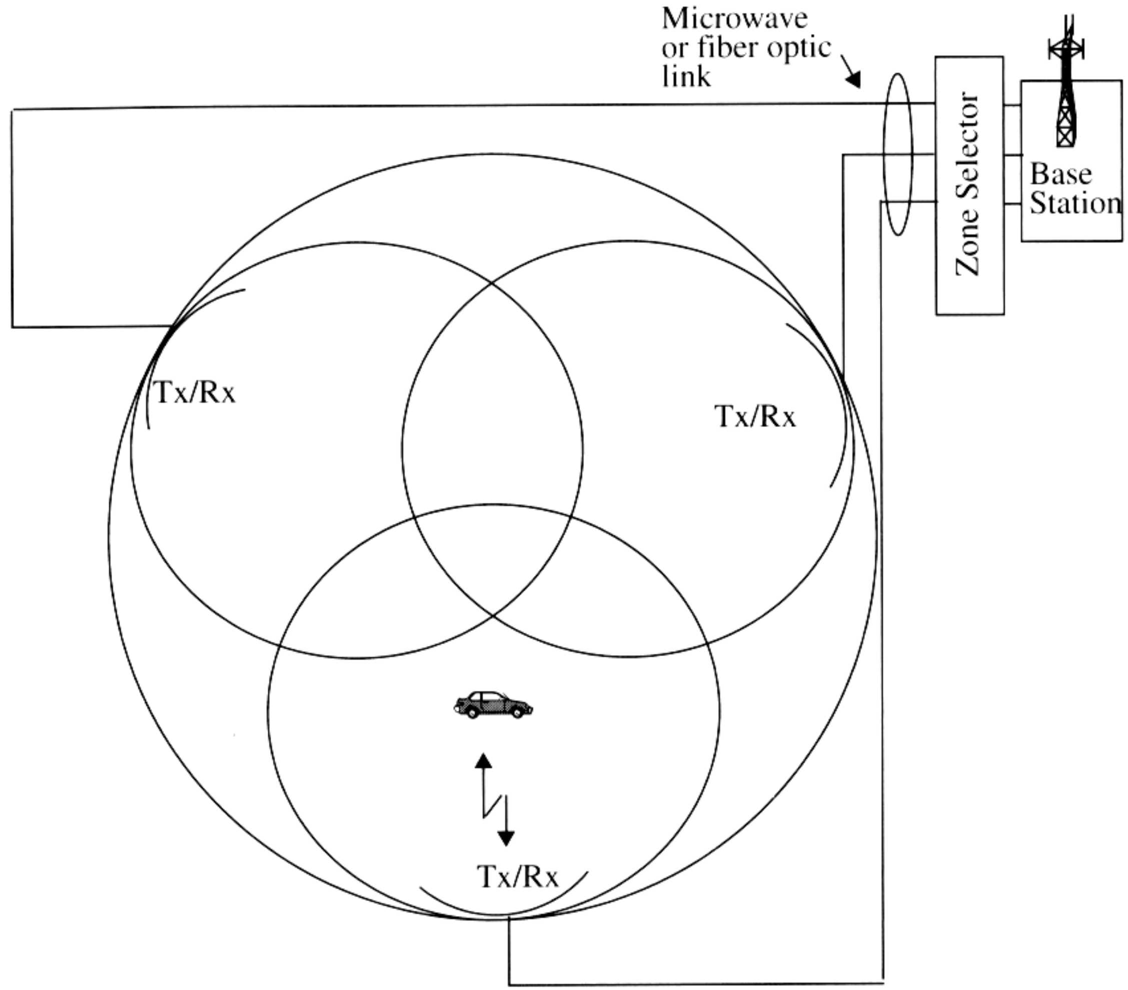


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

Zone Cell Concept

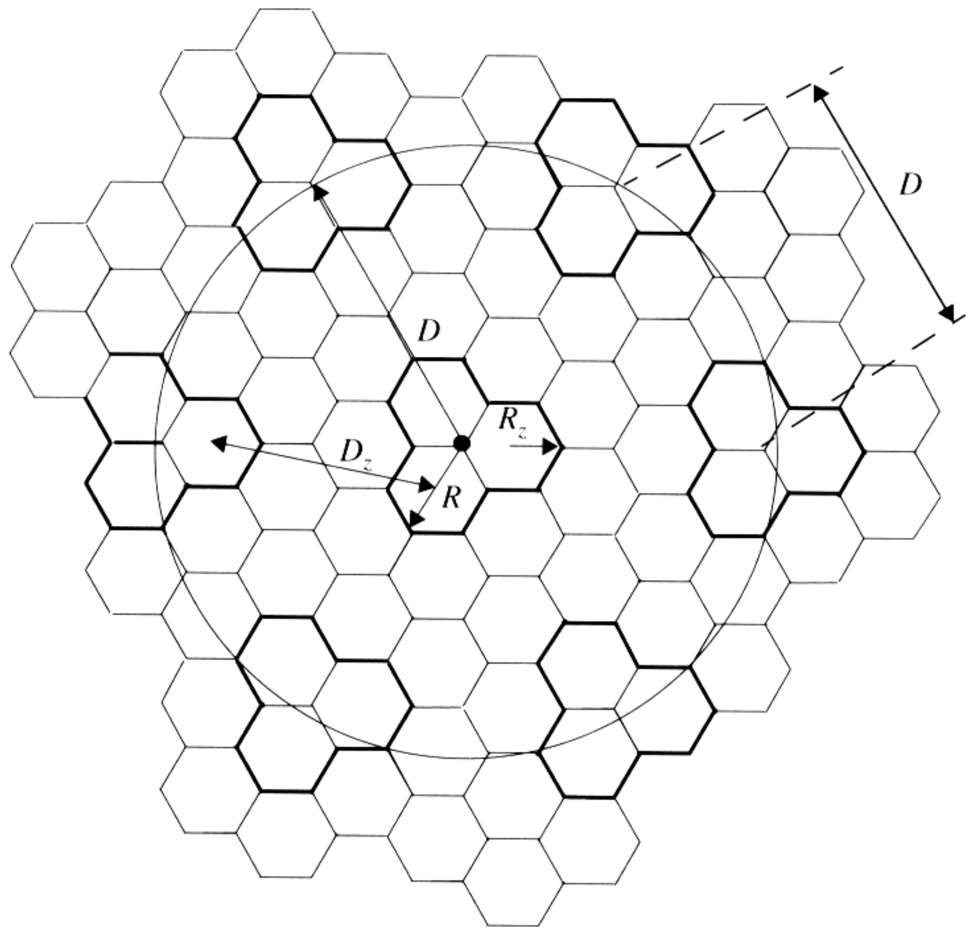


Figure 3.14 Define D, D_z, R, and R_z for a microcell architecture with $N = 7$. The smaller hexagons form zones and three hexagons (outlined in bold) together form a cell. Six nearest co-channel cells are shown.