3 . FREQUENCY MANAGEMENT AND CHANNEL ASSIGNMENT

FREQUENCY MANAGEMENT

- The function of frequency management is to divide the total number of available channels into subsets which can be assigned to each cell either in a fixed fashion or dynamically.
- Frequency management refers to designating setup channels and voice channels (done by the FCC), numbering the channels (done by the FCC), and grouping the voice channels into subsets (done by each system according to its preference).

FCC - Federal Communications Commission

CHANNEL ASSIGNMENT

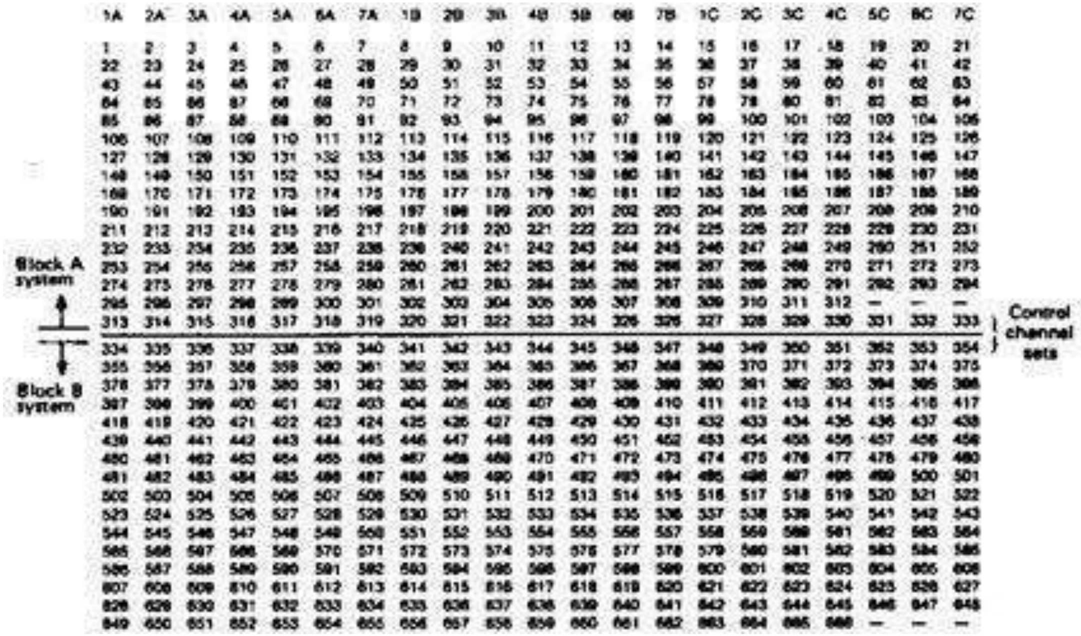
- Channel assignment refers to the allocation of specific channels to cell sites and mobile units.
- A fixed channel set consisting of one more subsets is assigned to a cell site on a long-term basis.
- During a call, a particular channel is assigned to a mobile unit on a short- term basis (.handled by the mobile telephone switching office (MTSO)).
- Ideally channel assignment should be based on causing the least interference in the system. However, most cellular systems cannot perform this way.

NUMBERING THE RADIO CHANNELS

- The total number of channels at present (January 1988) is 832.
- But most mobile units an systems are still operating on 666 channels. T
- A channel consists of two frequency channel bandwidths
  1. one in the low band
  2. one in the high band.
- Two frequencies in channel 1 are
  1. 825.030 MHz (mobile transmit) and
  2. 870.030 MHz (cell-site transmit).
- The two frequencies in channel 666 are
  1. 844.98 MHz (mobile transmit) and

2. 898 MHz (cell-site transmit).

- The 666 channels are divided into two groups:
    1. block A system and
    2. block B system. Each



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
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
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
418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438
439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459
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
544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564
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	612	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	—	—	—

Fig.4.1. Frequency management chart

- Each block has 333 channels
- The 42 set-up channels are assigned as follows.
    1. Channels 313-333 block A
    2. Channels 334-354 block B
- The voice channels are assigned as follows.
    1. Channels 1-312 (312 voice channels) block A
    2. Channels 355-666 (312 voice channels)block B
- New additional spectrum allocation of 10 MHz an additional 166 channels are assigned.
- Since a 1 MHz is assigned below 825 MHz (or 870 MHz).
- Additional channels will be numbered up to 849 MHz (or 894 MHz) and will then circle back .
- The last channel number is 1023.

- There are no Channels between channels 799 and 991.

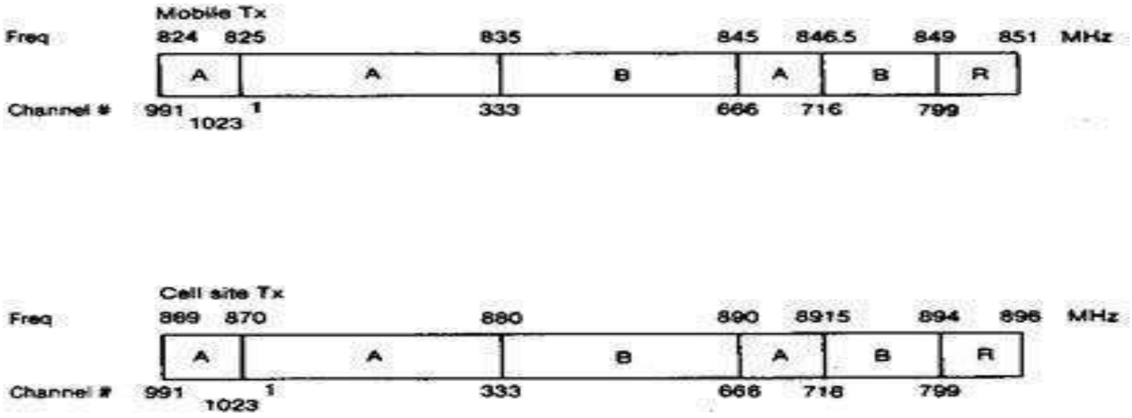


Fig. New additional spectrum allocationGROUPING INTO SUBSETS

GROUPING INTO SUBSETS

- voice channels for each system is 312.
- We can group these into any number of subsets. 21 set-up channels for each system.
- it is logical to group the 312 channels into 21 subsets.
- Each subset then consists of 16 channels.
- The 16 channels in each subset can be mounted on a frame and connected to a channel combiner.
- Wide separation between adjacent channels is required for meeting the requirement of minimum isolation.
- In a seven- cell frequency-reuse cell system each cell contains three subsets, iA+iB+iC, where i is an integer from 1 to 7.
- The total number of voice channels in a cell is about 45.

SET-UP CHANNELS

- Set-up channels, also called control channels are the channels designated to setup calls.
- A call always needs a set-up channel.
- Set-up channels can be classified by usage into two types:
  1. access channels and
  2. paging channels.
  - An access channel is used for the mobile-originating calls
- Paging channels for the land originating calls.

- In the most common types of cellular systems, one set-up channel is used for both access and paging.
- The forward set-up channel functions as the paging channel for responding to the mobile-originating calls.
- The reverse set-up channel functions as the access channel for the responder to the paging call.
- The forward set- up channel is transmitted at the cell site, and the reverse set-up channel is transmitted at the mobile unit.
- All set- up channels carry data information only.

ACCESS CHANNELS

- In mobile-originating calls, the mobile unit scans its 21 set-up channels and chooses the strongest one.
- Because each set-up channel is associated with one cell, the strongest set-up channel indicates which cell is to serve the mobile-originating calls.
- The mobile unit detects the system information transmitted from the cell site.
- Also, the mobile unit monitors the Busy/Idle status bits over the desired forward setup channel.
- When the idle bits are received, the mobile unit can use the corresponding reverse set-up channel to initiate a call.
- When the mobile unit first scans the 21 set-up channels in block A, two conditions can occur.

1. If no set-up channels of block A are operational, the mobile unit automatically switches to block B.
2. If a strong set-up signal strength is received but no message can be detected, then the scanner chooses the second strongest set-up channel. If the message still cannot be detected, the mobile unit switches to block B and scans to block B set-up channels.

The Operational Functions Are Described As Follows :

1. **Power Of A Forward Set-Up Channel [Or Forward Control Channel (FOCC)]:**

- The power of the set-up channel can be varied in order to control the number of incoming calls served by the cell.

- The number of mobile-originating calls is limited by the number of voice channels in each cell site, when the traffic is heavy, most voice channels are occupied and the power of the set-up channel should be reduced

- This will force the mobile units to originate calls from other cell sites, assuming that all cells are adequately overlapped.

2. **The Set-Up Channel Received Level**:

- The setup channel threshold level is determined in order to control the reception at the reverse control channel (RECC).
- If the received power level is greater than the given set-up threshold level, the call request will be taken.

3 **Change power at the mobile unit**:

When the mobile unit monitors the strongest signal strength from all Set-up channels and selects that channel to receive the messages, there are three types of message.

A. **Mobile Station Control Message.** This message is used for paging and consists of one, two, or four words -DCC, MIN, SCC and VMAX.

B. **System Parameter Overhead Message.** This message contains two words, including DCC, SID, CMAX, or CPA.

c. **Control-Filler Message.** This message may be sent with a system parameter overhead message, CMAC—a control mobile attenuation code (seven levels).

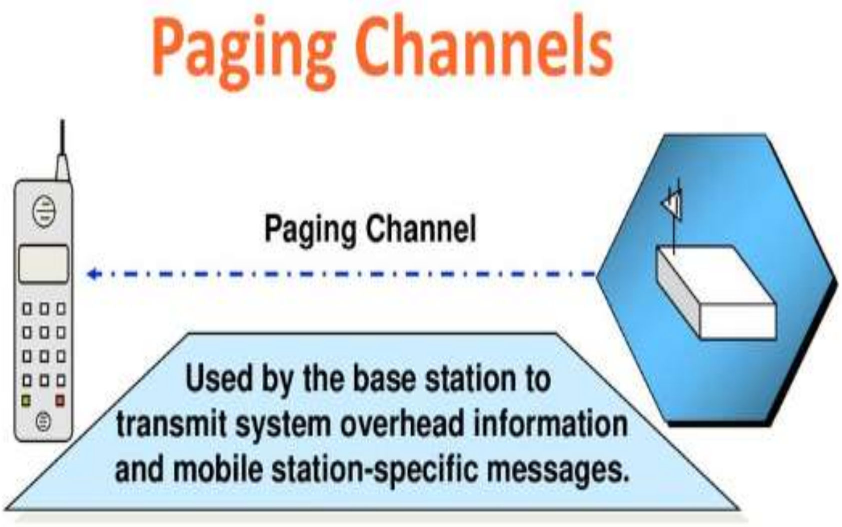
4 **Direct calls retry.**

- When a cell site has no available voice channels, it can send a direct call-retry message through the set-up channel.
- The mobile unit will initiate, the call from a neighboring cell which is on the list of neighboring cells in the direct call-retry message.

PAGING CHANNELS

- Paging Channel's main objective is to send out pages , that is , notifications of incoming calls , to the mobile stations
- Each cell site has been allocated its own setup channel (control channel).
- The assigned forward set-up channel (FOCC) of each cell site is used to page the mobile unit with the same mobile station control message.

- The simplest way is to page from all the cell sites.
- This can occupy a large amount of the traffic load.
- The other way is to page in an area corresponding to the mobile unit phone number.
- If there is no answer, the system tries to page in other areas. The drawback is that response time is sometimes too long.
- When the mobile unit responds to the page on the reverse set-up channel, the cell site which receives the response checks the signal reception level and makes a decision regarding the voice channel assignment based on least interference in the selected sector or underlay-overlay region.



Channel Assignment to the Cell Sites- Fixed Channel Assignment

- In a fixed channel assignment, the channels are usually assigned to the cell site for relatively long periods.
- Two types of channels are assigned :
    1. Set-up channels and
    2. Voice channels
- Setup-channels
    1. 21 setup channels assigned in a N=4,7,12 cell reuse patterns.
    2. If omni-directional antennas then each cell needs only one setup channel.
    3. This Leaves Unused set-up channels

Channel Assignment to Travelling Mobile Units

- When the traffic becomes heavier as more cars approach the city, the traffic pattern becomes non-uniform and the sites closest to the city or in the city, cannot receive the expected number of calls or handoffs in the morning because of the mobile unit antenna patterns.
- At night, as the cars move out of the city , the cell sites closest to the city would have a hard time handling off calls to the sites away from the city.
- To solve these problems , we have to use less transmitted power for both setup and voice channels for certain cell sites.
- We also have to raise the threshold level for reverse set-up channels and voice channels at certain cell sites in order to control the acceptance of incoming calls and handoff calls.
- Three methods can be used
    1. Underlay-overlay
    2. Frequency Assignment
    3. Tilted Antenna

Underlay-overlay :

- The traffic capacity at an omnidirectional cell or a directional cell can be increased by using underlay-overlay arrangement.
- The underlay is the inner circle , and the overlay is the outer ring.
- The transmitted powers of the voice channel at the site are adjusted for these two areas.
- Then different voice frequencies are assigned to each Underlaid-overlaid cell arrangements
    1. Underlay-overlay in omnicell
    2. Underlay-overlay in sectorized cells

3. Two-level handoff scheme

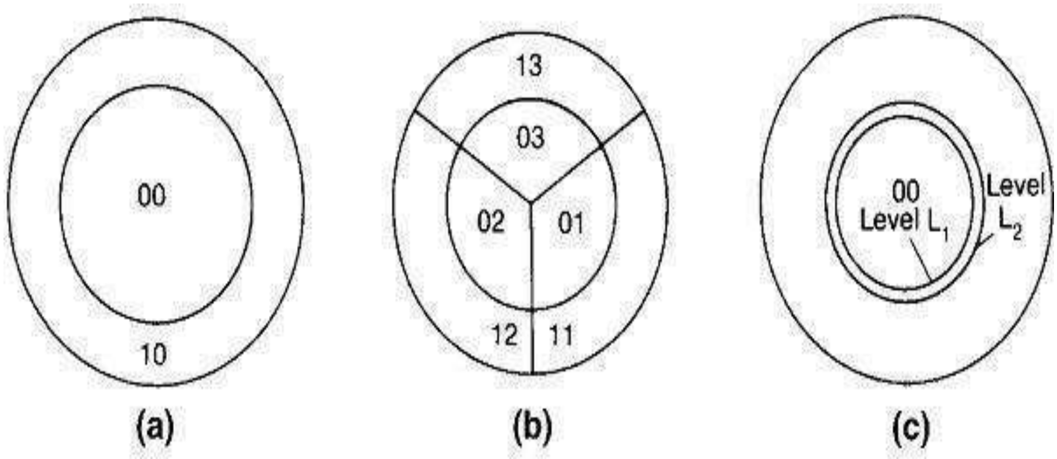


Fig.3.1.5. Under laid-overlaid cell arrangements.

(a) Underlay-overlay in omnicell; (b) Underlay-overlay in Sectorized cell;

(c) Two level handoff scheme

Frequency Assignment

- We assign the frequencies by a set of channels or any part of a set or more then one set of the total 21 sets.
- Borrowed frequency sets are used when needed.
- On the basis of coverage prediction, we can assign frequencies intelligently at one site or at one sector without interfacing with adjacent co-channel cells.

Tilted Antenna :

- Antenna tilting is more effective then decreasing antenna height, especially in areas of tall trees or at high sites.

FIXED CHANNEL ASSIGNMENT

1. Adjacent-Channel Assignment
2. Channel Sharing and Borrowing
3. Sectorization

Adjacent-Channel Assignment

- Adjacent Channel Assignment includes both neighbouring channel assignment and next-channel assignment.
- In an omnidirectional cell system , if one channel is allocated to the middle cell of seven cells, then the next channel cannot be assigned in the same cell.
- In a directional antenna system if one channel is assigned to a face , next channels cannot

be assigned to the same face or to the other faces in the same cell.

- Also, next channels cannot be assigned to the other two faces at the same cell site.

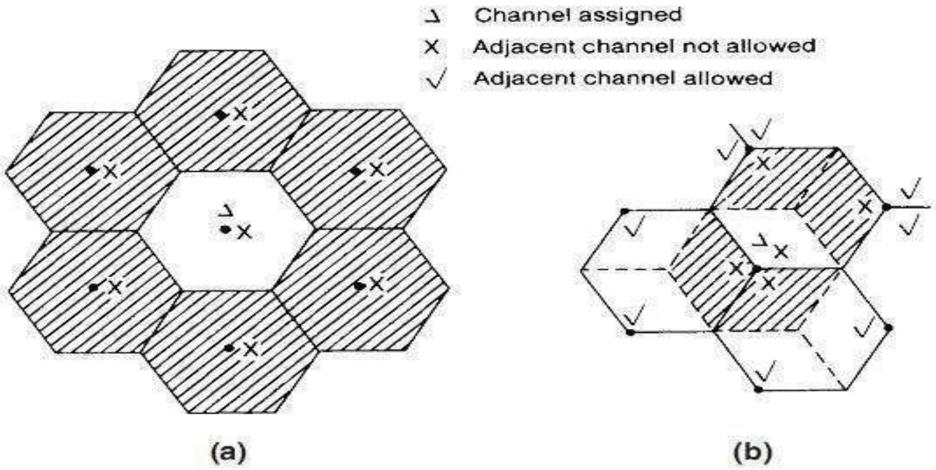


Fig.4.3 Adjacent channel assignment (a) Omni direction antenna cells; (b) Directional antenna cells

Channel Sharing and Borrowing

Channel Sharing

- Channel sharing is a short-term traffic-relief scheme.
- It is used when a particular cell needs more channels if there is an increase in the traffic demand.
- Sharing of the channel increases the trunking efficiency of channels.

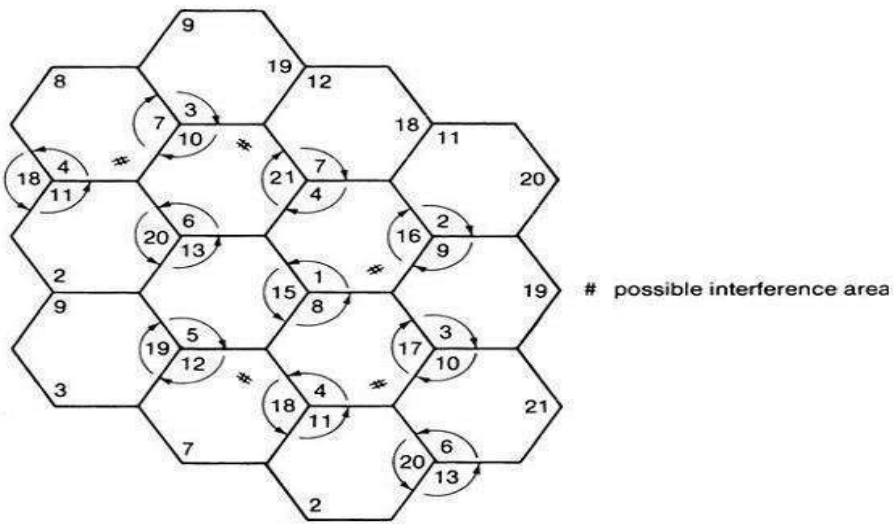


Fig.4.4. Channel sharing algorithm

CHANNEL BORROWING

- Channel Borrowing scheme is used primarily handled on a long-term basis and are generally used for slowly-growing systems.
- Channel Borrowing is also helpful in delaying cell splitting in some places where traffic is high.
- Cell splitting should be considered as the last option because it is costly.

Sectorization

- The total number of available channels can be divided into sets (subgroups) depending on the Sectorization of the cell configuration: the 120◦-sector system, the 60◦-sector system, and the 45◦-sector system.
- A seven cell system usually uses three 120◦ sectors per cell with total number of channels sets being 21.
- The sector angle can be reduced in order to assign more channels in one sector.

Comparision of Omnicells (Non-sectorized cells) and Sectorized Cells

OmniCells :

- If a k=7 frequency reuse pattern is used, the frequency sets assigned in each cell can be followed by the frequency management chart.
- If terrain is flat therefore k=12 is sometimes needed for reducing co-channel interference.
- For k=12, the channel reuse distance is D=6R, ot the co-channel reduction factor q=6.

SECTORIZED CELLS:

There are three basic types.

1. The 120◦-sector cell is used for both transmitting and receiving Sectorization. Each sector has an assigned a number of frequencies. Changing sectors during a call requires handoffs.
2. The 60◦-sector cell is used for both transmitting and receiving Sectorization. More handoffs than a 120◦ sector.
3. The 120◦ or 60◦-sector cell is used for receiving Sectorization only. In this case, the transmitting antenna is Omni directional. Therefore, no handoffs are required when changing sectors.

OVERLAID CELLS:

- To permit the two groups to reuse the channels in two different cell-reuse patterns of the same size, an "under laid" small cell is sometimes established at the same cell site as the large cell (see Fig. 7.5a).
- The "doughnut" (large) and "hole' (small) cells are treated as two different cells. They are usually considered as "neighboring cells".

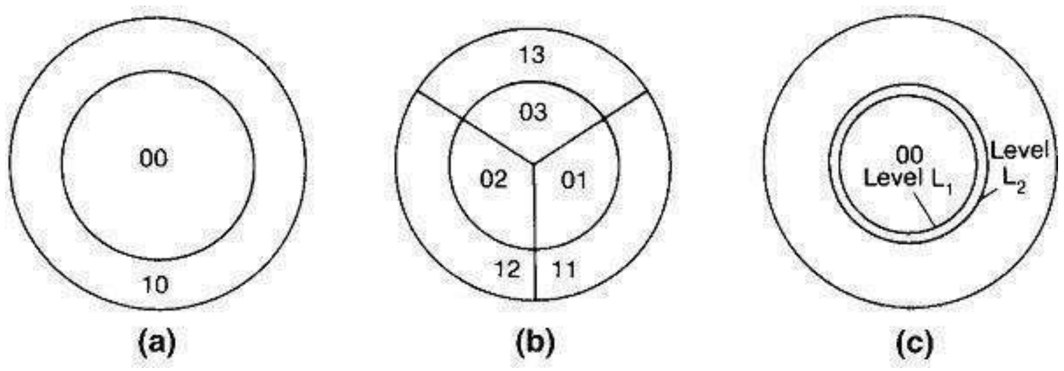


Fig.3.1.5. Under laid-overlaid cell arrangements.

(a) Underlay-overlay in omnicell; (b) Underlay-overlay in Sectorized cell; (c) Two level handoff scheme

- The use of either an Omni directional antenna at one site to create two sub ring areas or three directional antennas to create six subareas is illustrated in Fig. 3.15 b.
- As seen in Fig.3.1.5, a set of frequencies used in an overlay area will differ from a set of frequencies used in an underlay area in order to avoid adjacent-channel and co-channel interference.

NON -- FIXED CHANNEL ASSIGNMENT STRATEGY

1. **FIXED CHANNEL ASSIGNMENT:** In this algorithm, each cell assigns its own radio channels to the vehicles within its cell.
2. **DYNAMIC CHANNEL ASSIGNMENT:** In dynamic channel assignment (DCA), no fixed channels are assigned to each cell. Therefore, any channel in a composite of N radio channels can be assigned to the mobile unit.
3. **HYBRID CHANNEL ASSIGNMENT:** Hybrid channel assignment (HCA) is a combination of FCA and DCA. A portion of the total frequency channels will use FCA

and the rest will use DCA.

4. **BORROWING CHANNEL ASSIGNMENT:** Borrowing channel assignment (BCA) uses FCA as a normal assignment condition. When all the fixed channels are occupied, then the cell borrows channels from the neighboring cells.

5. **FORCIBLE-BORROWING CHANNEL ASSIGNMENT:** In forcible-borrowing channel assignment (FBCA), if a channel is in operation and the situation warrants it, channels must be borrowed from the neighboring cells and at the same time, another voice channel will be assigned to continue the call in the neighboring cell.

Simulation Process and Results

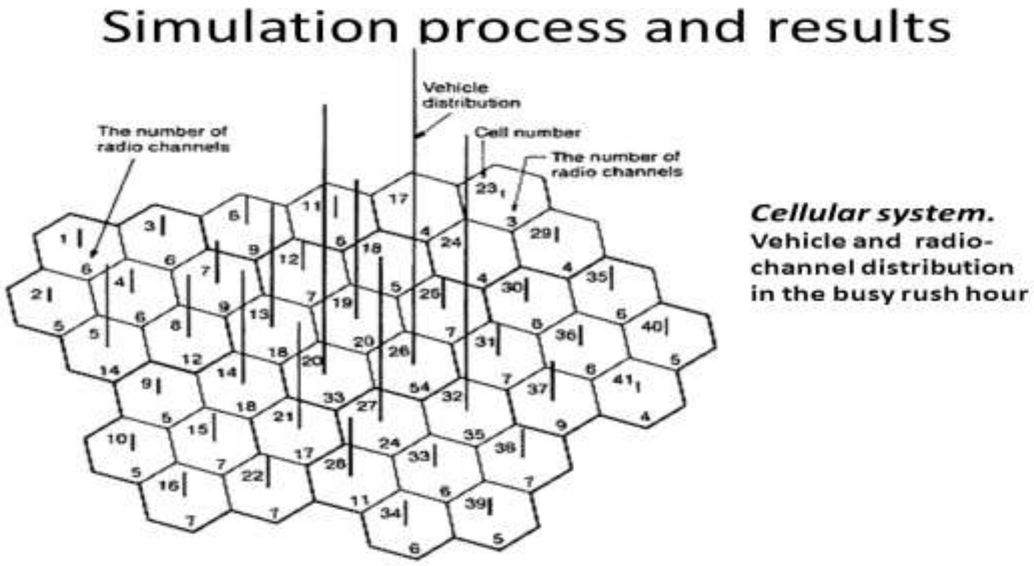
- On the basis of the FBCA , FCA and BCA algorithms, a seven-cell reuse pattern with an average blocking of 3 percent is assumed and the total traffic service in an area in 250 Erlangs.
- The traffic distributions are
    1. Uniform traffic distributions – 11 channels per cell ;
    2. A non uniform traffic distribution – the number of channels in each cell is dependent on the vehicle distribution.

The simulation model is described as follows :

1. Randomly select the cell (among 41 cells).
2. Determine the state of the vehicle in the cell (idle, off-hook, on-hook, and handoff).
3. In off-hook or handoff state , search for an idle channel . the average number is assumed to be 0.2 times per call. However, FBCA will increase the number of handoffs.

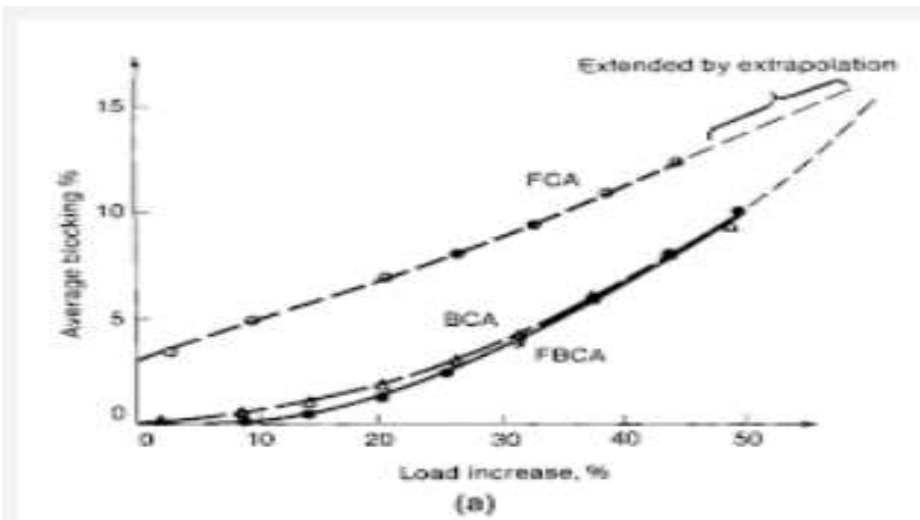
Off hook

On hook



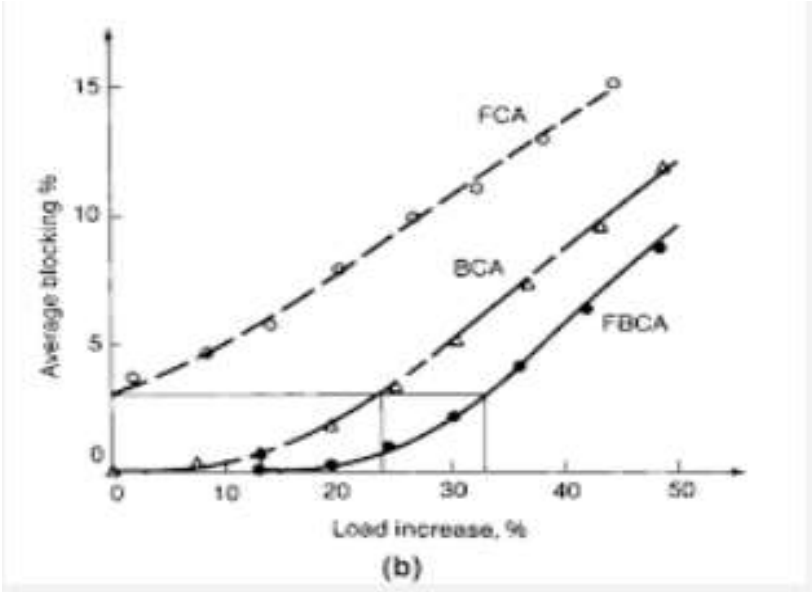
Average Blocking

- In a uniform traffic condition , the 3 percent blocking of both BCA and FBCA will result in a load increase of 28 percent, compared to 3 percent blocking of FCA.
- There is no difference between BCA and FBCA when a uniform traffic condition exists.



(a) average blocking in spatially uniform traffic distribution

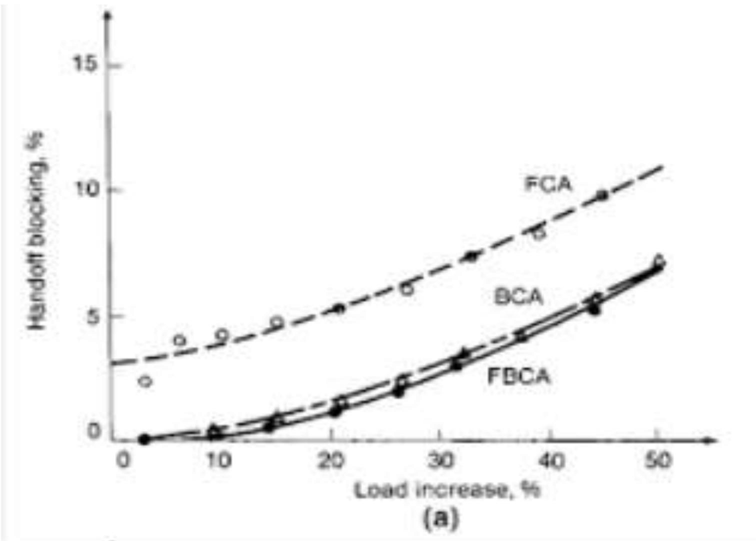
- In a non uniform traffic distribution , the load increase in BCA drops to 23 percent and that of FBCA increases to 33 percent as at an average blocking of 3 percent.



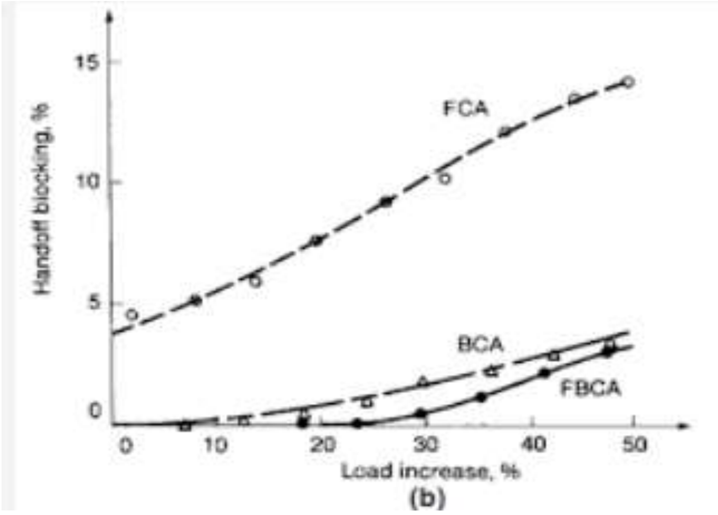
(b) average blocking in spatially " non uniform traffic distribution " .

HANDOFF BLOCKING

- Handoff Blocking is not considered as the regular cell blocking which can only occur at the cell setup stage. In both BCA and FBCA , load is increased almost equally to 30 percent , as compared to FCA at 3 percent handoff blocking in uniform traffic.
- For a non-uniform traffic distribution , the load increase of both BCA and FBCA at 4 percent blocking is about 50 percent , which is a big improvement, considering the reduction in interference and blocking. Otherwise , there would be multiple effects from interference in several neighbouring cells.



(a) handoff blocking in spatially uniform traffic distribution



(b) handoff blocking in spatially non uniform traffic distribution

PART – B

CELL COVERAGE FOR SIGNALAND TRAFFIC

- Cell coverage can be based on signal coverage or on traffic coverage.
- We have to examine the service area as occurring in one of the following environments:
- Human-made structures
    1. In a building area
    2. In an open area
    3. In a suburban area
    4. In an urban area
- Natural terrains
    1. Over flat terrain
    2. Over hilly terrain
    3. Over water
    4. Through foliage areas

SIGNAL REFLECTIONS IN FLAT AND HILLY TERRAIN

Ground incident angle and elevation point

- The ground incident angle θ is the angle of wave arrival incidentally pointing to the ground as shown in Fig. The ground elevation angle Φ is the angle of wave arrival at the mobile unit as shown in Fig.

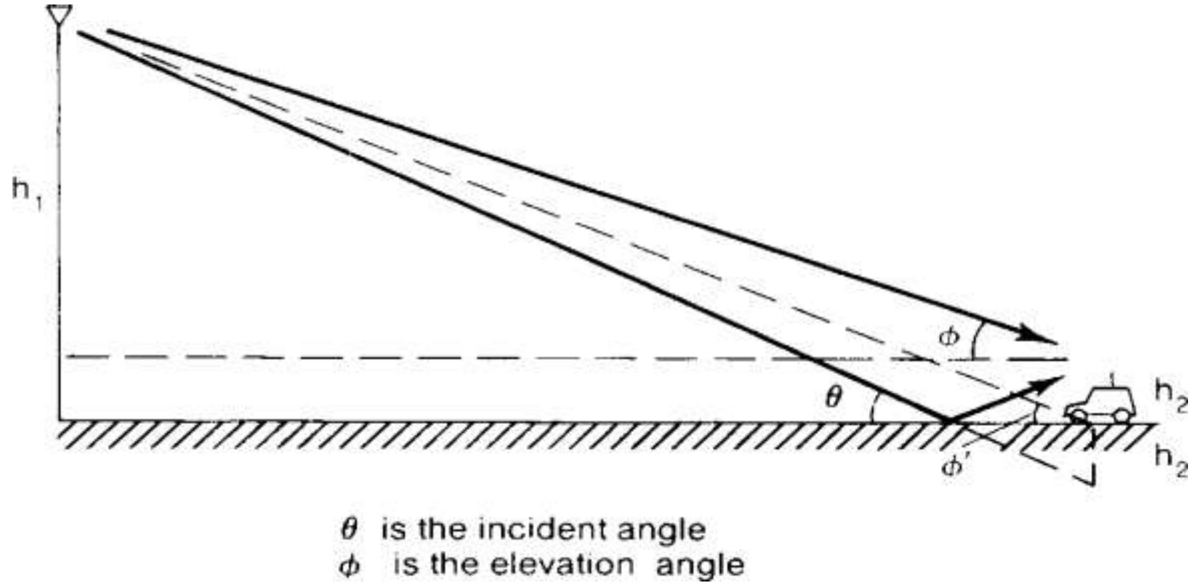


Figure Representation of Ground Incident Angle θ and Ground Elevation Angle φ

Ground incident angle and elevation point

- Based on Snell's law, the reflection angle and incident angle are the same.
- Since in graphical display we usually exaggerate the hilly slope and the incident angle by enlarging the vertical scale, as shown in Fig.
- The reflection point on a hilly slope can be obtained by following the same method as if the reflection point were on flat ground.

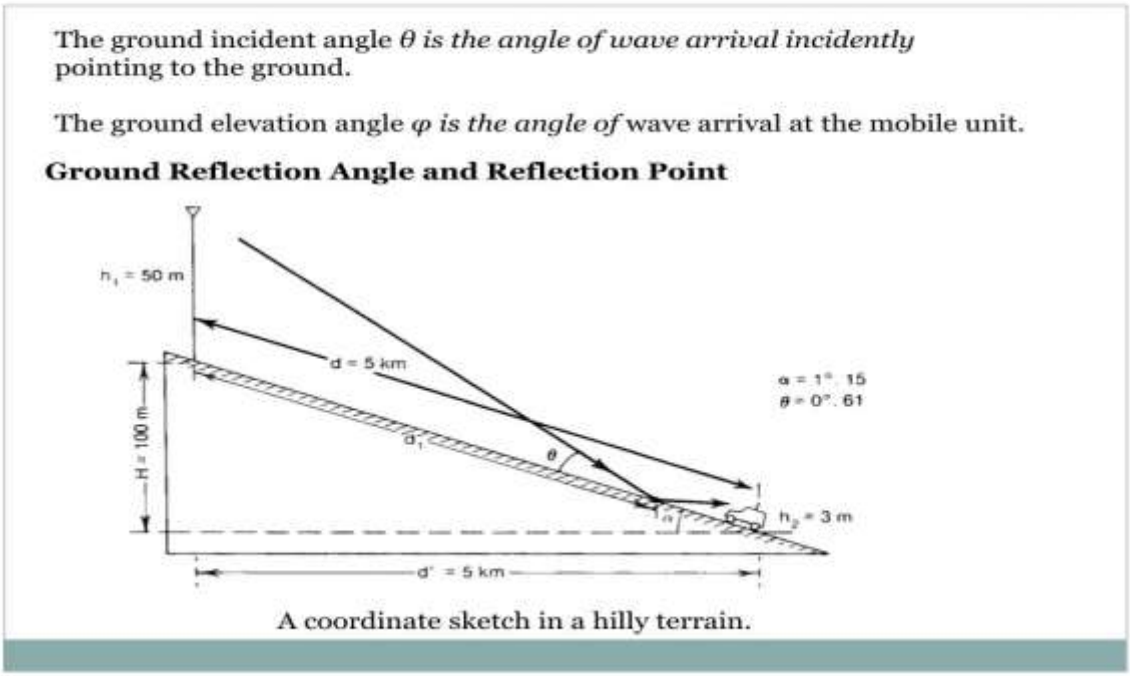


Fig Ground reflection angle and reflection point

EXAMPLE 8.2 *Let $h_1 = 50$ m, $h_2 = 3$ m, $d = 5$ km, and $H = 100$ m as shown in Fig. 8.2.*

(a) Using the approximate method ($d = d' = 5$ km), the slope angle α of the hill is

$$\alpha = \tan^{-1}\frac{100\text{ m}}{5\text{ km}} = 1.14576^\circ$$

the incident angle is

$$\theta = \tan^{-1}\frac{50\text{ m} + 3\text{ m}}{5\text{ km}} = 0.61$$

and the reflection point location from the cell-site antenna

$$d_1 = 50/\tan\theta = 4.717\text{ km.}$$

(b) Using the accurate method, the slope angle α of the hill is

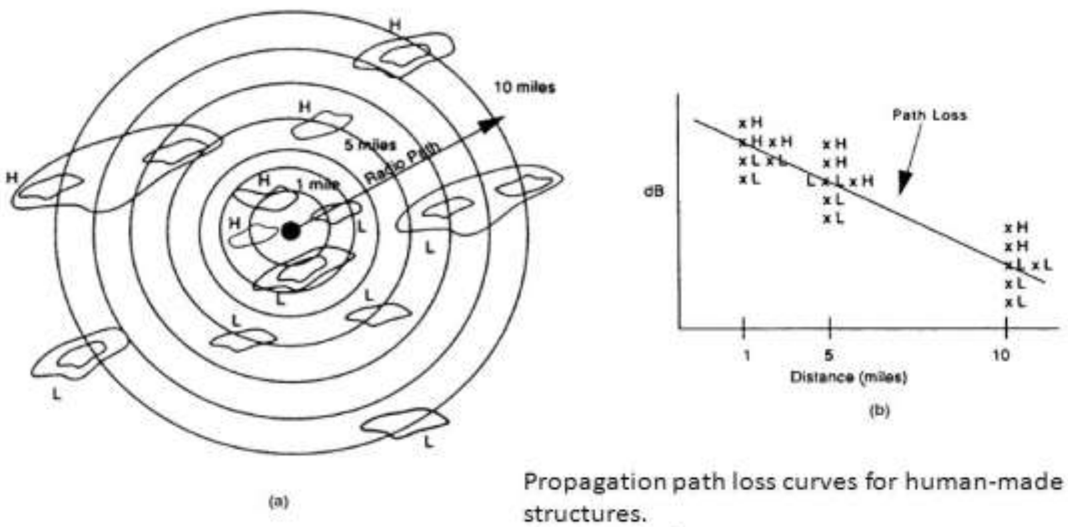
$$\alpha = \tan^{-1}\frac{100\text{ m}}{\sqrt{(5\text{ km})^2 - (100\text{ m})^2}} = \tan^{-1}\frac{100}{4999} = 1.14599^\circ$$

The incident angle θ and the reflection point location d_1 are the same as above.

EFFECT OF HUMAN MADE STRUCTURES

- Because the terrain configuration of each city is different , and the human –made structure of each city is also unique.

Effect of the Human-Made Structures



Propagation path loss curves for human-made structures.
(a) For selecting measurement areas
(b) path loss phenomenon.

- The way to factor out the effect due to the terrain configuration from the man-made structures is to work out a way to obtain the path loss for the area.

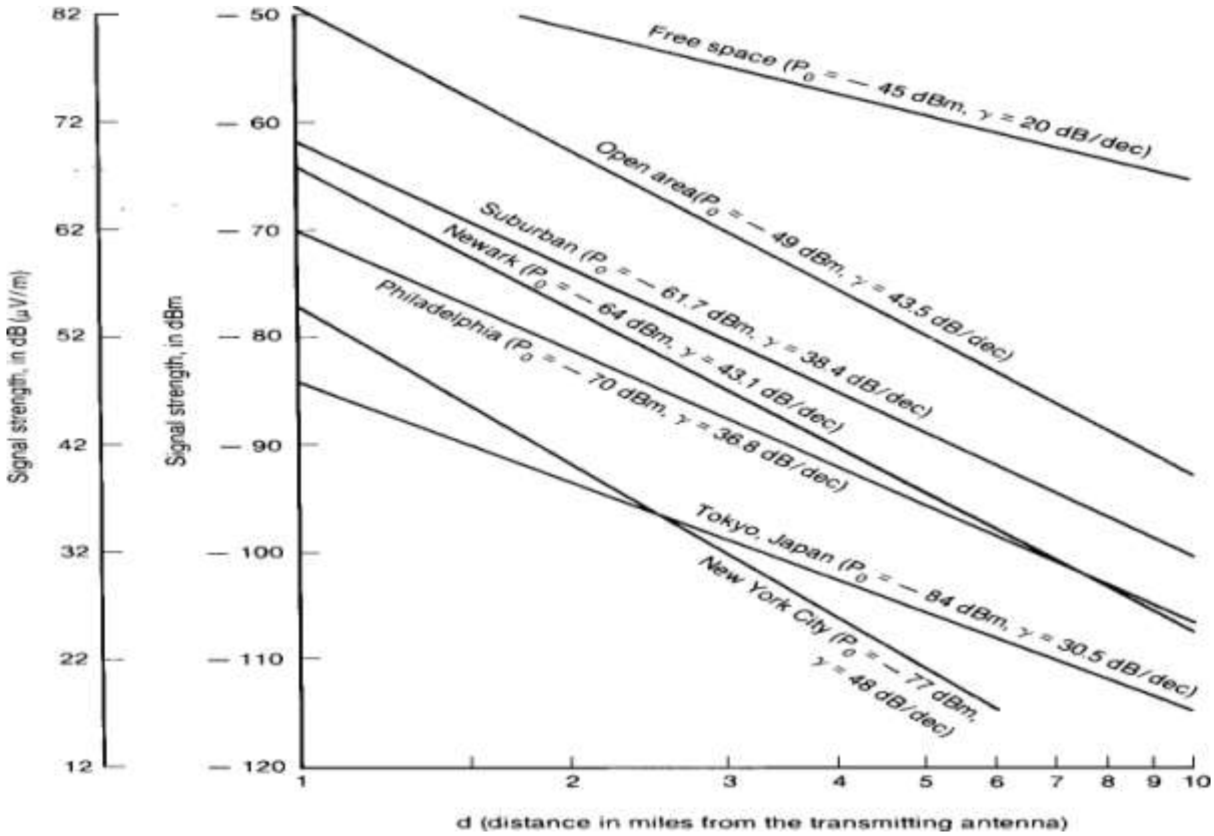
- The path loss curve obtained on virtually flat ground indicates the effects of the signal loss to solely human-made structures.
- We may have to measure signal strengths at those high spots and also at the low spots surrounding the cell sites as shown in figure.
- Then the average path loss slope , which is a combination of measurements from high spots and low spots along different , radio paths in a general area, represents the signal received as if it is from a flat area affected only by a different local human-made structured environment.
- We are using 1-mi intercepts (or, alternatively , 1-km intercepts) as a starting point for obtaining the path loss curve.
- Therfore, the differences is area-to-area prediction curves are due to the different man-made structures.
- The measurements made in urban areas are different from those made in suburban and open areas.
- Any area-to-area prediction model can be used as a first step toward achieving the point-to-pointprediction model.
- Area-to-area prediction model which is described here can be represented by two parameters:

(1) the 1-mi (or 1-km) intercept point

(2) the path-loss slope.

- The 1-mi intercept point is the power received at a distance of 1 mi from the transmitter.
- There are **two** general approaches to finding the values of the two parameters experimentally.

1. . Compare the area of interest with an area of similar human-made structures which presents a curve as shown.



(b) **Propagation path loss in different cities.**

2. If the human-made structures of a city are different from the cities listed in previous figure, a simple measurement should be carried out.

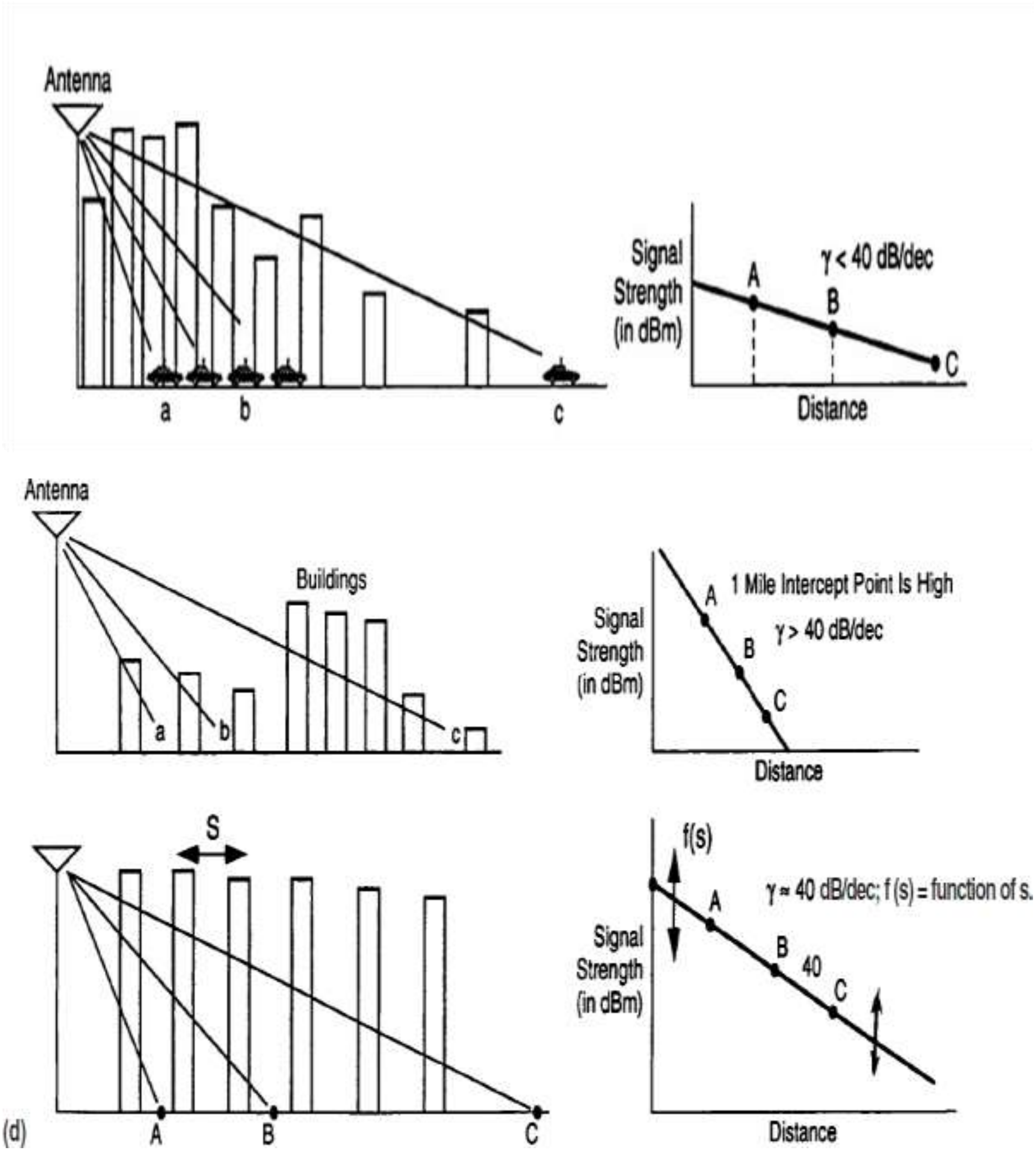
- Set up a transmitting antenna at the center of a general area.
- As long as the building height is comparable to the others in the area, the antenna location is not critical. .
- Take six or seven measured data points around the 1-mi intercept and around the 10-mi boundary based on the high and low spots. .
- Then compute the average of the 1 mi data points and of the 10 mi data points.
- By connecting the two values, the path-loss slope can be obtained.
- If the area is very hilly, then the data points measured at a given distance from the base station in different locations can be far apart.
- In this case, we may take more measured data points to obtain the average path-loss slope.
- If the terrain of the hilly area is generally sloped, then we have to convert the data points that were measured on the sloped terrain to a flat terrain in that area.
- The conversion is based on the effective antenna-height gain as

$$\Delta G = \text{effective antenna-height gain} = 20 \log \frac{h_e}{h_1}$$

Where , h1 is the actual height and he is the effective antenna height at either the 1- or 10-mi locations.

3 . **Path-loss Phenomena**

- The plotted curves shown in the previous figure have different 1-mi intercepts and different slopes.



(d) Explanation of the path-loss phenomenon.

- When the base station antenna is located in the city , then the 1-.mi. intercept could be very lo.w and the slope is flattened out, as shown by T>okey's curve.

- When the base station is located ou.tside the city, the intercept could be much higher and the slope is deeper, as shown by the Newark curve.
- When the Stru.ctures are unifo.rmly distributed, depending on the density, the 1-.mi intercept could be high or lo.w , but the slope may also keep. At 40 db/dec.

PHASE DIFFERENCE BETWEEN A DIRECT PATH AND A GROUND-REFLECTED PATH

- Based on a direct path and a ground reflected path, the equation indicates a two-wave model which is used to understand the path-loss phenomenon in a mobile radio environment.

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda} \right)^2 \left| 1 + a_v e^{j\Delta\phi} \right|^2$$

Where

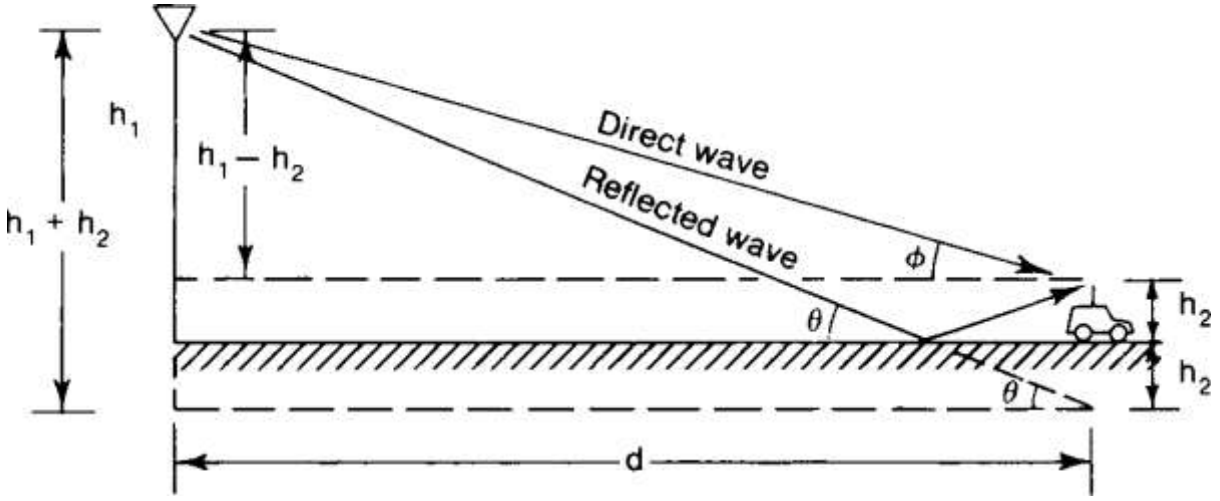
av = the reflection coefficient

φ = the phase difference between a direct path and a reflected path

P0 = the transmitted power

d = the distance

λ = the wavelength



- In a mobile environment av = −1 because of the small incident angle of the ground wave caused by a relatively low cell-site antenna height. Thus,

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$

$$= P_0 \frac{2}{(4\pi d/\lambda)^2}(1 - \cos\Delta\phi) = P_0 \frac{4}{(4\pi d/\lambda)^2} \sin^2 \frac{\Delta\phi}{2}$$

where

$$\Delta\phi = \beta\Delta d$$

and Δd is the difference, $\Delta d = d_1 - d_2$ from Fig. 8.4.

$$d_1 = \sqrt{(h_1 + h_2)^2 + d^2}$$

and

$$d_2 = \sqrt{(h_1 - h_2)^2 + d^2}$$

Because Δd is much smaller than either d_1 or d_2,

$$\Delta\phi = \beta\Delta d \approx \frac{2\pi}{\lambda}\frac{2h_1h_2}{d}$$

Then the received power of becomes :

$$P_r = P_0 \frac{\lambda^2}{(4\pi)^2 d^2} \sin^2 \frac{4\pi h_1 h_2}{\lambda d}$$

If φ is less than 0.6 rad, then sin(φ/2) ≈ φ/2, cos(φ/2) ≈ 1 and equation simplifies to

$$P_r = P_0 \frac{4}{16\pi^2 (d/\lambda)^2} \left(\frac{2\pi h_1 h_2}{\lambda d}\right)^2 = P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

From Equation, we can deduce two relationships as follows:

$$\Delta P = 40 \log \frac{d_1}{d_2} \quad \text{(a 40 dB/dec path loss)}$$

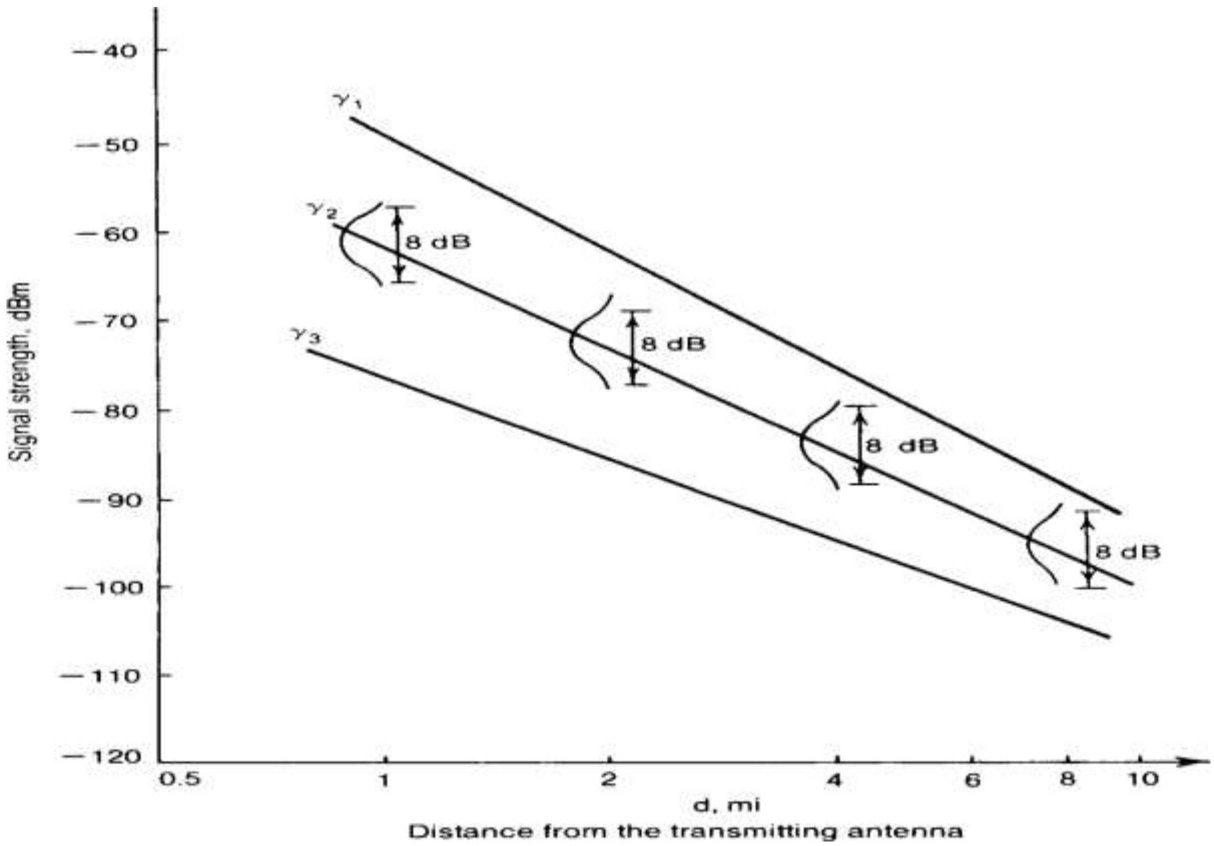
$$\Delta G = 20 \log \frac{h_1'}{h_1} \quad \text{(an antenna height gain of 6 dB/oct)}$$

where ΔP is the power difference in decibels between two different path lengths and ΔG is the gain (or loss) in decibels obtained from two different antenna heights at the cell site.

$$\Delta G' = 10 \log \frac{h_2'}{h_2} \quad \text{(an antenna-height gain of 3 dB/oct)}$$

Straight Line Path Loss Slope

- The path-loss curves are obtained from many different runs at many different areas.
- In the experimential data, the data-loss deviation is 8 dB across the distance from 1.6 to 15 Km (> 1 to 10 mi) where the general terrain contours are not generally Flat.



- The path-loss curve i.s y. The received power can be expressed as

are the same in different runs, the signal strength data measured at that distance would be used to calculate the mean value for the path loss at that distance. In the experimental data, the path-loss deviation is 8 dB across the distance from 1.6 to 15 km (1 to 10 mi) where the general terrain contours are not generally flat. Figure 8.5 depicts this. The path-loss curve is γ. The received power can be expressed as

$$P_r = P_0 - \gamma \log \frac{r}{r_0} \tag{8.2-11}$$

The slope γ is different in different areas, but it is always a straight line in a log scale. If $\gamma = 20$ is a free-space path loss, $\gamma = 40$ is a mobile path loss.

8.2.5.1 Confidence Level.[30] A confidence level can only be applied to the path-loss curve when the standard deviation σ is known. In American suburban areas, the standard deviation $\sigma = 8$ dB. The values at any given distance over the radio path are concentrated close to the mean and have a bell-shaped (normal) distribution. The probability that 50 percent of the measured data are equal to or below a given level is[27]

$$P(x \geq C) = \int_C^{\infty} \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-A)^2/2\sigma^2} dx = 50\% \tag{8.2-12}$$

where A is the mean level obtained along the path-loss slope, which is shown in Eq. (8.2-11) as

$$A = P_0 - \gamma \log \frac{r_1}{r_0}$$

Thus, level A corresponds to the distance r_1. If level A increases, the confidence level decreases, as shown in Eq. (8.2-12).

$$P(x \geq C) = P\left(\frac{x - A}{\sigma} \geq B\right) \tag{8.2-13}$$

Let $C = B\sigma + A$. The different confidence levels are shown in Table 8.2. We can see how to use confidence levels from the following example.

EXAMPLE 8.4 *From the path-loss curve, we read the expected signal level as −100 dBm at 16 km (10 mi). If the standard deviation σ = 8 dB, what level would the signal equal or exceed for a 20 percent confidence level?*

TABLE 8.2 The Different Confidence Levels

$P(x \leq C)$, %	$C = B\sigma + A$
80	$-0.85\sigma + A$
70	$-0.55\sigma + A$
60	$-0.25\sigma + A$
50	A
40	$0.25\sigma + A$
30	$0.55\sigma + A$
20	$0.85\sigma + A$
16	$1\sigma + A$
10	$1.3\sigma + A$
2.28	$2\sigma + A$

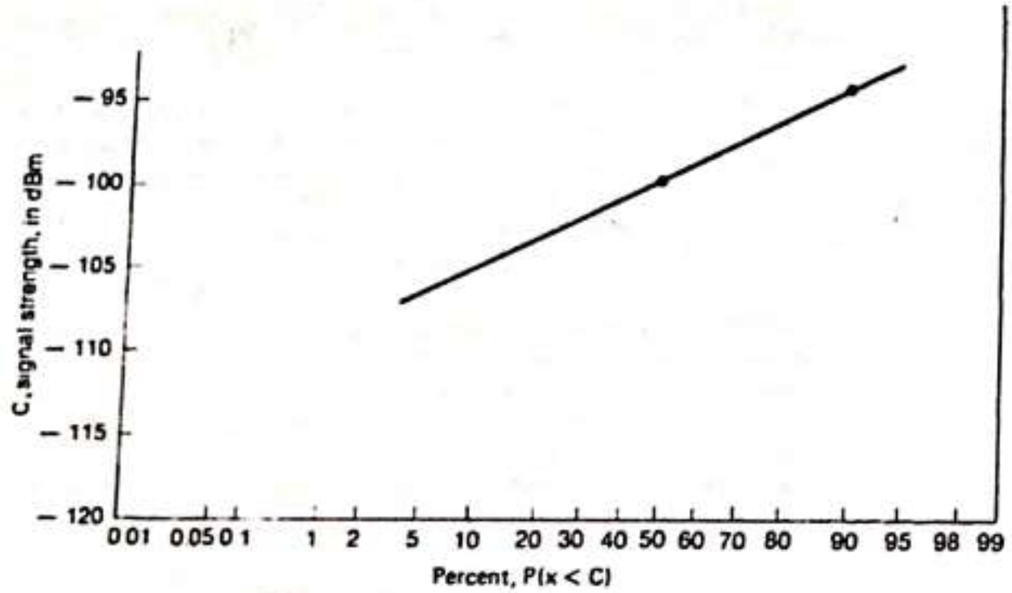


FIGURE 8.6 A log-normal curve.

$$P\left(\frac{x-A}{\sigma} \geq B\right) = 20\% \qquad x \geq B\sigma + A \qquad \text{(E8.4-1)}$$

or from Table 8.2 we obtain

$$x \geq 0.85 \times 8 + (-100) = -93.2\,\text{dBm}$$

The log normal curve with a standard deviation of 8 dB is shown in Fig. 8.6.

GENERAL FORMULA FOR MOBILE

- Here We are only interested in a general propagation path-loss formula in a general mobile radio environment , which could be a suburban area.

$$P_r = (P_t - 40) - 61.7 - 38.4 \log \frac{r_1}{1\text{ mi}} + 20 \log \frac{h_1}{100\text{ ft}} + 10 \log \frac{h_2}{10\text{ ft}} + (G_t - 6) + G_m$$

- Above equation is simplified as

$$P_r = P_t - 157.7 - 38.4 \log r_1 + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

- Where P_t is in decibels above 1mW, r_1 is in miles , h_1 and h_2 are in feet , and G_1 and G_m are in decibels. Equation is used for suburban areas

- We may like to change equation to a general formula by using P_t 10 mi as a reference

$$P_r = P_t - 156 - 40\log r_1 + 20\log h_1 + 10\log h_2 + G_t + G_m$$

where $Pr = Pt - K$ at $r1 = 1$ mile, $h1 = h2 = 1$, and $Gt = Gm = 0$. The value of K and γ will be different and need to be measured in different human-made environment.

- The most general formula is expressed as follows

$$P_r = P_t - K - \gamma\log r_1 + 20\log h_1 + 10\log h_2 + G_t + G_m$$

Propagation Over Water And Flat Open area

- Propagation over water or fiat open area is becoming a big concern because it is very easy to interfere with other cells if we do not make the correct arrangements.
- Interference resulting from propagation over the water can be controlled if we know the cause.
- As shown in Fig 10.1 Since the two antennas, one at the cell site and the other at the mobile unit, are well above sea level, two reflection points are generated.
- The one reflected from the ground is close to the mobile unit; the other reflected from the water is away from the mobile unit.
- We recall that the only reflected wave we considered in the land mobile propagation is the one reflection point which is always very close to the mobile unit.
- The point -to-point transmission between the fixed stations over the water or flat open land can be estimated as follows. The received power P, can be expressed as (see Fig.10.2)

$$P_r = P_t\left(\frac{1}{4\pi d/\lambda}\right)^2\left|1 + a_v e^{-j\phi_v}\exp(j\Delta\phi)\right|^2$$

where P_t = the transmitted power

d = distance between two stations

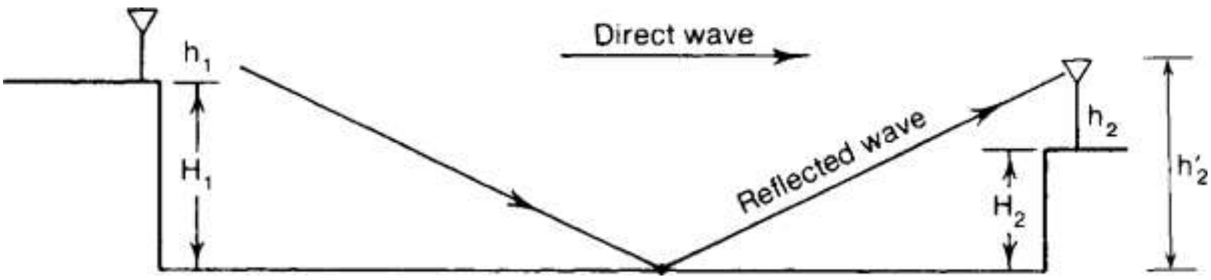
λ = wavelength

a_v, ϕ_v = amplitude and phase of a complex reflection coefficient, respectively

$\Delta\phi$ is the phase difference caused by the path difference Δd between the direct wave and the reflected wave, or

$$\Delta\phi = \beta\Delta d = \frac{2\pi}{\lambda}\Delta d$$

$$P_0 = \frac{P_t}{(4\pi d/\lambda)^2}$$



Propagation between two fixed stations over water or flat open land.

- The $a_v e^{-j\phi_v}$ are the complex reflection coefficients and can be found from the formula .

$$a_v e^{-j\phi_v} = \frac{\epsilon_c \sin\theta_1 - (\epsilon_c - \cos^2\theta_1)^{1/2}}{\epsilon_c \sin\theta_1 + (\epsilon_c - \cos^2\theta_1)^{1/2}}$$

When the vertical incidence is small, *θ is very small and*

$$a_v \approx -1 \quad \text{and} \quad \phi_v = 0$$

And thereafter, the equation then becomes:-

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}\left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$

$$= P_0(2 - 2\cos\Delta\phi)$$

as Δφ is a function of Δd and Δd can be obtained from the following calculation. The effective antenna height at antenna 1 is the height above the sea level.

$$h_1' = h_1 + H_1$$

Therefore, we can set up five conditions:

1. $P_r < P_0$. The received power is less than the power received in free space;

$$2 - 2\cos\Delta\phi < 1 \quad \text{or} \quad \Delta\phi < \frac{\pi}{3}$$

2. $P_r = 0$; that is,

$$2 - 2\cos\Delta\phi = 0 \quad \text{or} \quad \Delta\phi = \frac{\pi}{2}$$

3. $P_r = P_0$; that is,

$$2 - 2\cos\Delta\phi = 1 \quad \text{or} \quad \Delta\phi = \pm 60^\circ = \pm\frac{\pi}{3}$$

4. $P_r > P_0$; that is,

$$2 - 2\cos\Delta\phi > 1 \quad \text{or} \quad \frac{\pi}{3} < \Delta\phi < \frac{5\pi}{3}$$

5. $P_r = 4P_0$; that is,

$$2 - 2\cos\Delta\phi = \max \quad \text{or} \quad \Delta\phi = \pi$$

The effective antenna height at antenna 2 is the height above the sea level.

$$h_2' = h_2 + H_2$$

where h1 and h2 are actual heights and H1 and H2 are the heights of hills. In general, both antennas at fixed stations are high, so the reflection point of the wave will be found toward the middle of the radio path. The path difference d can be obtained as

$$\Delta d = \sqrt{(h_1' + h_2')^2 + d^2} - \sqrt{(h_1' - h_2')^2 + d^2}$$

Because $d \gg h_1'$ and h_2', then

$$\Delta d \approx d\left[1 + \frac{(h_1' + h_2')^2}{2d^2} - 1 - \frac{(h_1' - h_2')^2}{2d^2}\right] = \frac{2h_1'h_2'}{d}$$

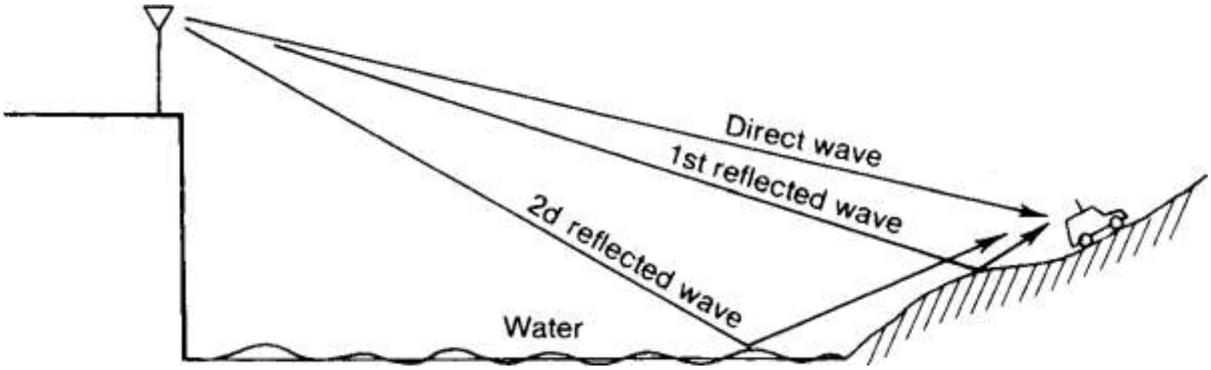
Then, equation becomes

$$\Delta\phi = \frac{2\pi}{\lambda}\frac{2h_1'h_2'}{d} = \frac{4\pi h_1'h_2'}{\lambda d}$$

Land-to-Mobile Transmission Over Water

- There are always two equal-strength reflected waves, one from the water and one from the proximity of the mobile unit, in addition to the direct wave.

- Therefore, the reflected power of the two reflected waves can reach the mobile unit without noticeable attenuation. The total received power at the mobile unit would be obtained by summing three components.



$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}\left|1 - e^{j\Delta\phi_1} - e^{j\Delta\phi_2}\right|^2$$

Where Δφ1 and Δφ2 are the path-length difference between the direct wave and two reflected waves,

respectively. Because Δφ1 and Δφ2 are very small usually for the land-to-mobile path, then

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}\left|1 - \cos\Delta\phi_1 - \cos\Delta\phi_2 - j(\sin\Delta\phi_1 + \sin\Delta\phi_2)\right|^2$$

Follow the same approximation for the land-to-mobile propagation over water.

$$\cos\Delta\phi_1 \approx \cos\Delta\phi_2 \approx 1 \quad \sin\Delta\phi_1 \approx \Delta\phi_1 \quad \sin\Delta\phi_2 \approx \Delta\phi_2$$

Then,

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}\left|-1 - j(\Delta\phi_2 + \Delta\phi_2)\right|^2$$

$$= \frac{P_t}{(4\pi d/\lambda)^2}\left[1 + (\Delta\phi_1 + \Delta\phi_2)^2\right]$$

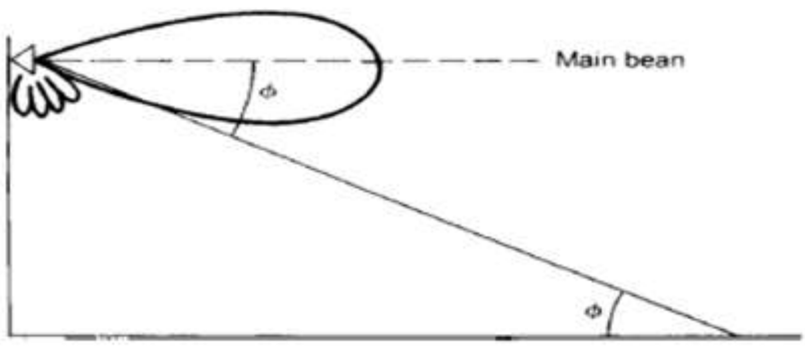
In most practical cases, *Δφ1 + Δφ2 < 1; then* $(\Delta\varphi 1 + \Delta\varphi 2)^2$ *<< 1 and the equation reduces* to

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}$$

PROPAGATION IN NEAR-IN DISTANCE

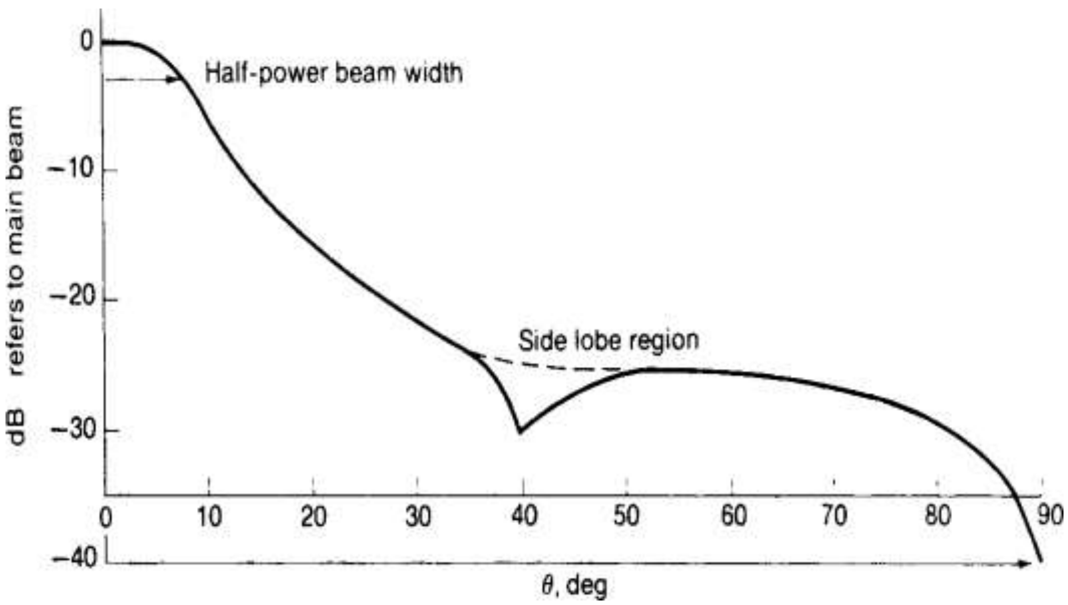
- We are using the suburban area as an example.
- At the 1-mi intercept, the received level is −61.7 dBm based on the reference set of parameters; that is, the antenna height is 30 m (100 ft).
- If we increase the antenna height to 60 m (200 ft), a 6-dB gain is obtained. From 60 to 120 m (20 to 400-ft), another 6 dB is obtained.
- At the 120-m (400-ft) antenna height, the mobile received signal is the same as that received at the free space.
- The antenna pattern is not isotropic in the vertical plane.

PROPAGATION IN NEAR-IN DISTANCE



Elevation angle of the shadow of the antenna pattern.

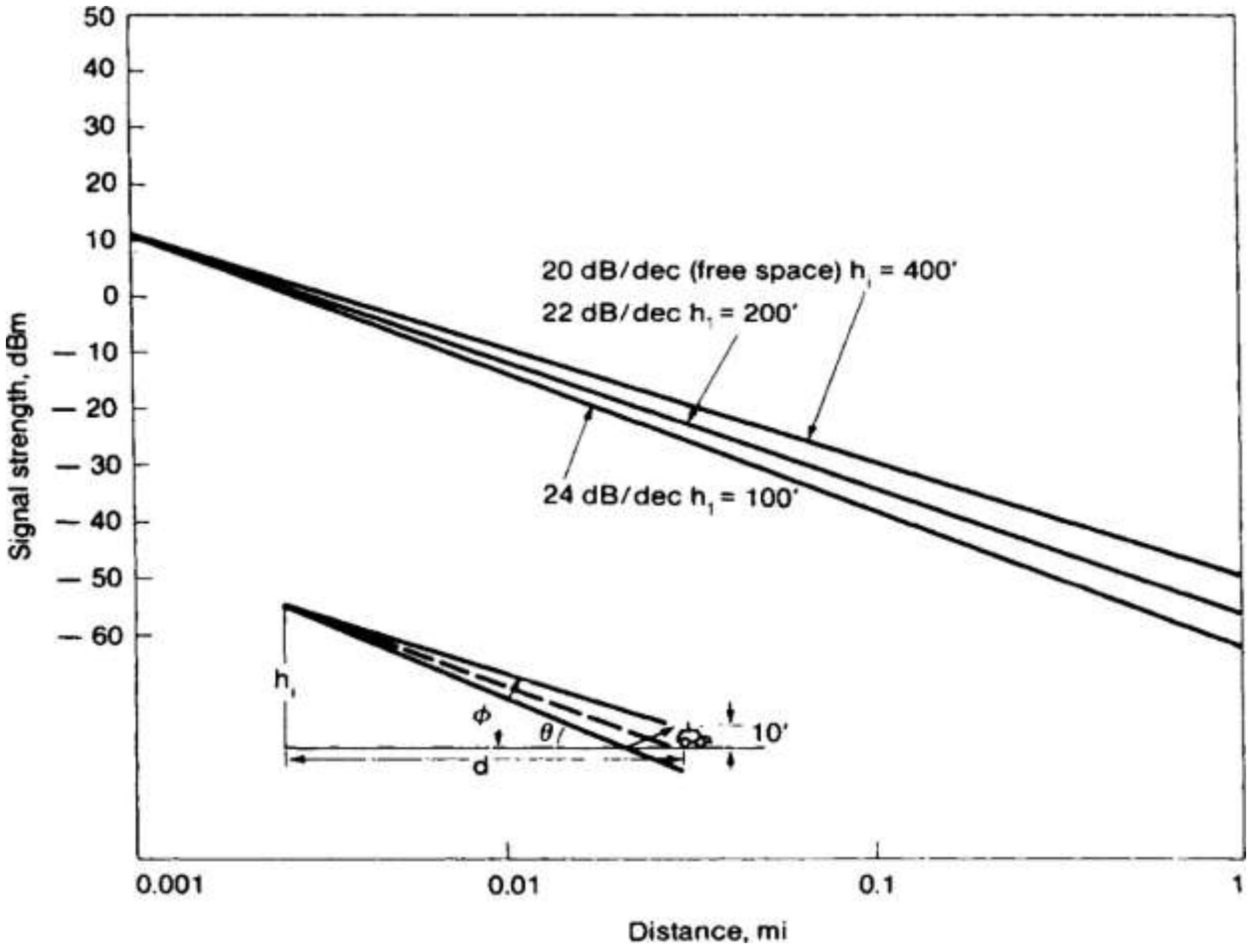
Curves for near-in propagations



A typical 6-dB omni-directional antenna beam width.

- The reduction in signal reception can be found in the figure and is listed in the table below.
- At d = 100 m (328 ft) [mobile antenna height = 3 m (10 ft)], the incident angles and elevation angles are 11.77◦ and 10.72◦, respectively.

Antenna Height h_1, m (ft)	Incident Angle θ, Degrees	Elevation Angle ϕ, Degrees	Attentuation α, dB
90 (300)	30.4	29.6	21
60 (200)	21.61	20.75	16
30 (100)	11.77	10.72	6



LONG-DISTANCE PROPAGATION

- The advantage of a high cell site is that it covers the signal in a large area, especially in a noise-limited system where usually different frequencies are repeatedly used in different areas.

- However, we have to be aware of the long-distance propagation phenomenon.
- A noise-limited system gradually becomes an interference-limited system as the traffic increases.
- The interference is due to not only the existence of many co-channels and adjacent channels in the system, but the long-distance propagation also affects the interference.

Within an Area of 50-mi Radius

- For a high site, the low-atmospheric phenomenon would cause the ground wave path to propagate in a non-straight-line fashion.
- The wave path can bend either upward or downward.
- Then we may have the experience that at one spot the signal may be strong at one time but weak at another.

At a Distance of 320 km (200 mi)

- Tropospheric wave propagation prevails at 800 MHz for long-distance propagation; sometimes the signal can reach 320 km (200 mi) away.
- The wave is received 320 km away because of an abrupt change in the effective dielectric constant of the troposphere.
- The dielectric constant changes with temperature, which decreases with height at a rate of about 6.5◦C/km and reaches −50◦C at the upper boundary of the troposphere.
- In tropospheric propagation, the wave may be divided by refraction and reflection.
- **Tropospheric refraction:** This refraction is a gradual bending of the rays due to the changing effective dielectric constant of the atmosphere through which the wave is passing.
- **Tropospheric reflection*:*** This reflection will occur where there are abrupt changes in the dielectric constant of the atmosphere. The distance of propagation is much greater than the line-of-sight propagation.
- **Moistness*:*** Water content has much more effect than temperature on the dielectric constant of the atmosphere and on the manner in which the radio waves are affected.
- The water vapor pressure decreases as the height increases.
- Tropospheric wave propagation does cause interference and can only be reduced by

umbrella antenna beam patterns, a directional antenna pattern, or a low-power low-antenna approach.

FINDING THE ANTENNA HEIGHT

1. Find the specular reflection point. Take two values from two conditions stated as follows.
    a) Connect the image antenna of the cell-site antenna to the mobile antenna ; the intercept point at the ground level is considered as a potential reflection point.
    b) Connect the image antenna of the mobile antenna to the cell-site antenna ; the intercept point at the ground level is considered as a potential reflection point.

   Between two potential reflection points we choose the point which is close to the mobile unit to be the real one because more energy would be reflected to the mobile unit at the point.
2. Extend the reflected ground plane. The reflected ground plane which the reflection point is on can be generated by drawing a tangent line to the point where the ground curvature is , then extending the reflected ground plane to the location of the cell-site antenna.

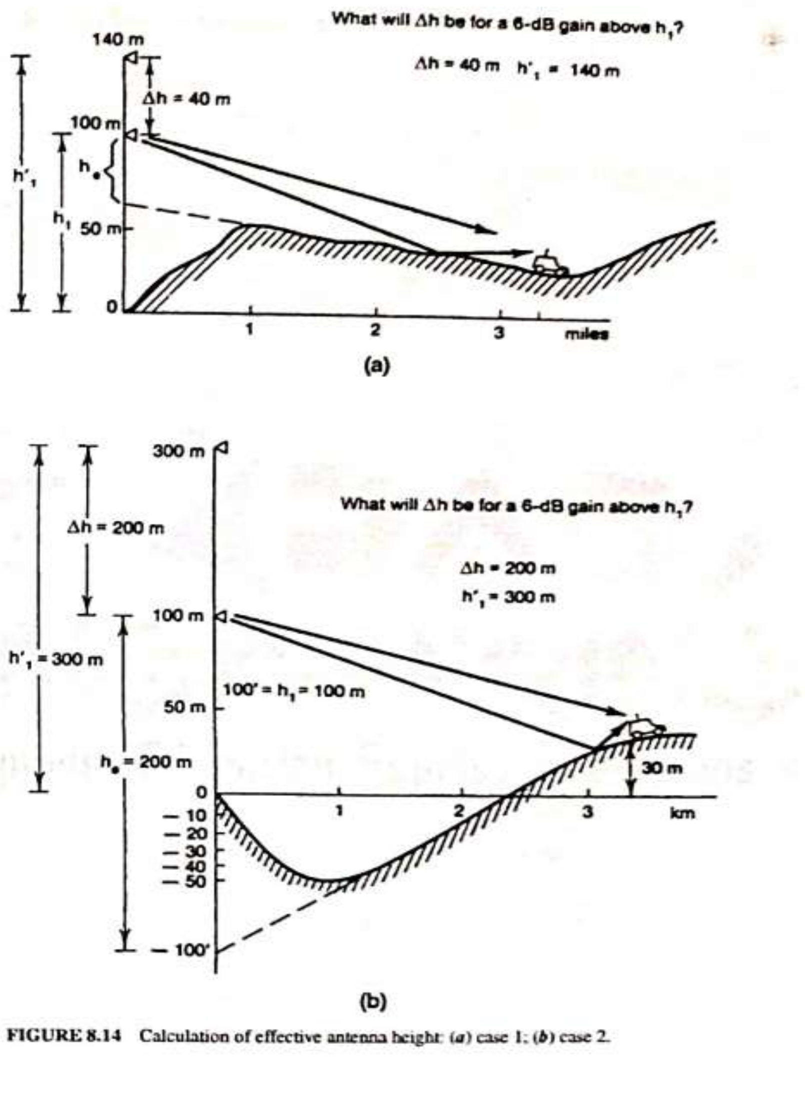


FIGURE 8.14 Calculation of effective antenna height: (*a*) case 1; (*b*) case 2.

3. Measure the effective antenna height . The effective antenna height is measured from the point where the reflected ground plan and cell site antenna location meet. Between these two cases shown in fig.4.14, h_e equals 40m in fig.4.14a and 200m in fig.4.14b. The actual antenna height h_1 100m.
4. Calculate the antenna-height gain deltaG . The formula of deltaG is expressed as

$$G = 20 \log \frac{h_e}{h_1} \qquad (8.7\text{-}1)$$

Then the ΔG from Fig. 8.14*a* is

$$\Delta G = 20 \log \frac{40}{100} = -8 \text{ dB} \qquad \text{(a negative gain in Fig. 8.14}a\text{)}$$

The ΔG from Fig. 8.14*b* is

$$\Delta G = 20 \log \frac{200}{100} = 6 \text{ dB} \qquad \text{(a positive gain in Fig. 8.14}b\text{)}$$

We have to realize that the antenna-height gain ΔG changes as the mobile unit moves along the road. In other words, the effective antenna height at the cell site changes as the mobile unit moves to a new location, although the actual antenna remains unchanged.

FORM OF A POINT-TO-POINT MODEL

General formula

We form the model as follows:

$$P_r = \begin{cases} \text{Nonobstructive path} \\ = \underbrace{P_{r_0} - \gamma \log \frac{r}{r_0} +}_{\text{By human-made structure}} \quad \underbrace{20 \log \frac{h'_e}{h_1} + \alpha}_{\text{By terrain contour}} \\ \\ \text{Obstructive path} \\ = P_{r_0} - \gamma \log \frac{r}{r_0} + \quad 20 \log \frac{h''_e}{h_1} + L + \alpha \\ = \underbrace{P_{r_0} - \gamma \log \frac{r}{r_0} +}_{\text{By human-made structure}} \quad \underbrace{L + \alpha \ (\text{when } h''_e \approx h_1)}_{\text{By terrain contour}} \\ \text{Land-to-mobile over water} = \text{a free-space formula} \end{cases}$$

Remarks

1. The P_r cannot be higher than that from the free-space path loss
2. The road orientation , when it is within 2 mi from the cell site, will affect the received power at the mobile unit . The received power at the mobile unit traveling along an-line road can be 10 dB higher then that along a perpendicular road.
3. α is the corrected factor obtained from the condition.
4. The foliage loss would be added depending on each individual situation.Avoid choosing a cell site in the forest. Be sure that the antenna height at the cell site is higher than the top of the trees.

MERITS OF POINT-TO-POINT MODEL

- The point-to-point model reduces the uncertainty range by including the detailed terrain contour information in the path-loss predictions.
- The differences between the predicted values and the measured ones for the point-to-point model were determined in many areas.

- In the following discussion, we compare the differences shown in the Whippany, N.J., area and the Camden- Philadelphia area.
- First, we plot the points with predicted values at the x-axis and the measured values at the y-axis, shown in Fig. 4.
- The dots are data from the Whippany area, and the crosses are data from the Camden-Philadelphia area. Most of them, except the one at 9 dB, are close to the line of prediction without error.
- In other areas, the differences were slightly larger. However, the standard deviation of the predicted value never exceeds the measured one by more than 3 dB.
- The standard deviation range is much reduced as compared with the maximum of 8 dB from area-to-area models.
- The point-to-point model is very useful for designing a mobile cellular system with a radius for each cell of 10 mi or less.
- The point-to-point prediction model is a basic tool that is used to generate a signal coverage map, an interference area map, a handoff occurrence map, or an optimum system design configuration.