UNIT-IV
Frequency Management

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 set-up channels and voice channels, numbering the channels, and grouping the voice channels into subsets.
- Channel assignment refers to the allocation of specific channels to cell sites and mobile units.
- Allocation of specific channels to cell site on long term basis is called ‘fixed channel assignment’.
- Allocation of specific channels to cell site on short term basis is called ‘dynamic 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 (i.e., in response to any channel among the total available channels).

The terms "frequency management" and "channel assignment" often create some confusion. *Frequency management* refers to designating set-up 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).

Numbering of channels

- The total number of channels at present (January 1988) is 832. But most mobile units and systems are still operating on 666 channels.
- A channel consists of two frequency channel bandwidths, one in the low band and one in the high band.
- For example frequencies of channel 1 are 825.03MHz(mobile transmit) and 870.03MHz(cell site transmit)
- Two frequencies of channel 666 in AMPS systems are

  844.98MHz(mobile transmit) and 889.98MHz(cell site transmit)

Numbering of channels contd---

- Total available spectrum in AMPS (Advanced Mobile Phone Systems) is 40MHz.
- 40MHz Band Width is divided into 666 channels.
- Each channel has a bandwidth of 60KHz i.e., 40MHz/666 which is approximately equal to 60KHz.
- Each channel means Duplex channel(30KHz for forward channel and 30KHz for reverse channel).

Numbering of channels contd---

- The 666 channels are divided into two groups: block A system and block B system. Each market (i.e., each city) has two systems. Each block has 333 channels, as shown in Fig.
- The 42 set-up channels are assigned as follows.

  Channels 313-333 block A

  Channels 334-354 block B
- The voice channels are assigned as follows.

Channels 1-312 (312 voice channels) block A

Channels 355-666 (312 voice channels) block B

- These 42 set-up channels are assigned in the middle of all the assigned channels to facilitate scanning of those channels by frequency synthesizers.

FIGURE . Frequency-management chart of AMPS system

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	569	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
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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	—	—	—

Block A system

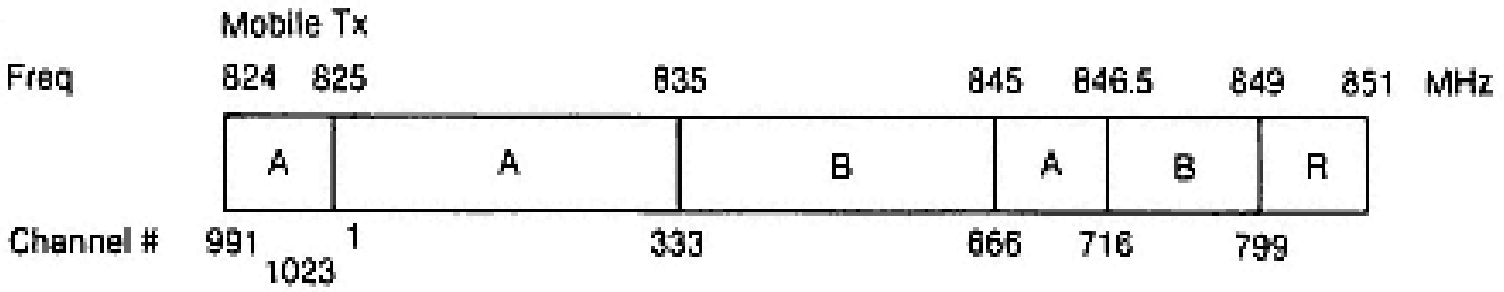
Block B system

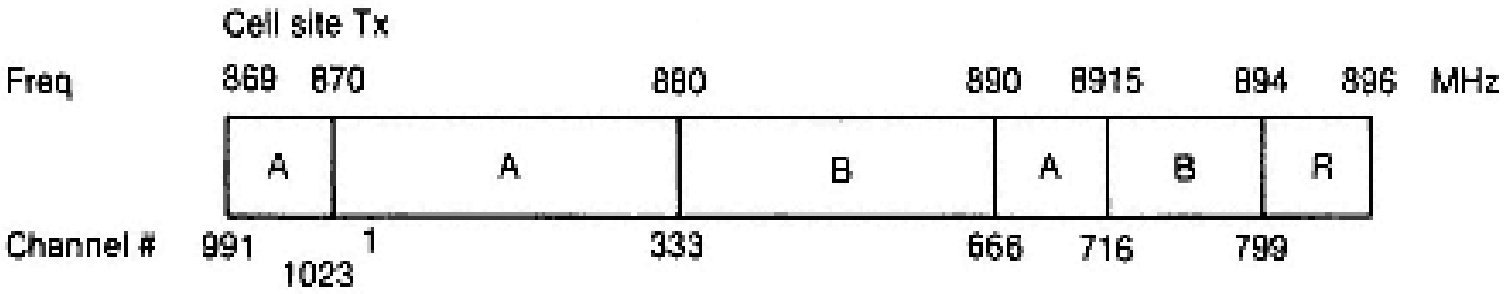
Control channel sets

Numbering of channels contd---

- FCC(Federal Communication Commission) allocated new additional spectrum of 10MHz.
- 10MHz means an additional of166(10MHz/60KHz) channels are assigned.
- Out of 166, 83 channels are assigned to block A and 83 are assigned to block B system.
- Since a 1MHz is assigned below 825 MHz(or 870MHz), in future, 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.

New additional spectrum allocation





Grouping into Subsets

- The number of voice channels in each system is 312. We can group these into any number of subsets.
- Number of setup channels in each block is 21. So it is logical to group these 312 channels into 21 subsets.
- Each subset has 16 channels.
- In each set, the closest adjacent channel is 21 channels away .
- In a seven cell frequency reuse cell system, each cell contains three subsets i.e, iA+iB+iC, where i is an integer from 1 to 7.
- The minimum separation between three subsets is 7 channels.

Set-upchannels

- Set-up channels, also called control channels, are the channels designated to set-up calls.
- Without set up channel also, system can be operated.
- If we are choosing such a system then all 333 channels in each system(block A and block B) can be voice channels
- However each mobile unit must then scan 333 channels continuously and detect the signaling for its call.
- A customer who wants to initiate a call must scan all the channels and find an idle (unoccupied) one to use.

Set-upchannels contd-----

- In each block of system we have 21 setup channels.
- The number 21 is derived from a seven cell frequency reuse pattern with three 120 degree sectors per cell, or a total of 21 sectors, which require 21 setup channels.
- Set up channels are classified into
  1. Access channels 2.Paging channels
- An access channel is used for mobile originating calls and paging channel is used for land originating calls
- In a low traffic areas access and paging channels are same
- Every two way channel contains two 30KHz bandwidths.
- A set up channel also consists of two simplex channels one is forward set up channel(BS to MS) and another one is reverse set up channel(MS to BS).

Set-upchannels contd-----

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

Access channels

- Generally Access channels are used for mobile originating calls.
- Access channels carries information from mobile unit to cell site.
- In mobile- originating calls, the mobile unit scans its 21 setup 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 set-up channel
- When the Idle bits are received, the mobile unit can use the corresponding reverse set-up channel to initiate a call.

Access channels contd------

- Operational functions
  - 1.Power of forward setup channel: The power of the set-up channel can be varied in order to control the number of incoming calls served by the cell. When the traffic is high most voice channels are occupied and the power of the set-up channel should be reduced in order to reduce the coverage of the cell for the incoming calls originating from the mobile unit.
  - 2.The set-up channel received level: If the received power level is greater than the given set-up threshold level, call request will be taken.
  - 3.Direct call retry: When a cell site has no available voice channels, it can send a direct call -retry message through the set-up channel.

Paging channels

- Each cell site has been allocated its own set-up channel (control channel).
- The assigned forward set-up channel of each cell site is used to page the mobile unit with the same mobile station control message.
- No simulcast interference as same message is transmitted using different cell sites.
- Draw back is that paging process is too long.
- When mobile unit responds to paging channel, voice channel is assigned depending on signal level and interference level.

Frequency spectrum utilization

- Increase channels by using narrow banding, spread spectrum, or time division
- Increasing spatial spectrum frequency reuse
- Frequency management and channel assignment
- Improving spectrum efficiency time
- Reducing load of invalid calls
  - Voice storage service for no-answere calls
  - Call forwarding
  - Call waiting
  - Queuing

- Self location scheme:- selects a set up channel and makes mobile originating call.in this method mobile unit prevents from sending the necessary information regarding its location to cell site.
- Autonomous registration
- Traffic load on set up channels
- Separation between access and paging

Definition of channel assignment

- Channel assignment refers to the allocation of specific channels to cell sites and mobile units.
- Channel assignment to the cell sites-fixed channel assignment.
- In fixed channel assignment, the channels are usually assigned to the cell-site for relatively long periods. Two types of channels are assigned
  - Set-up channels
  - Voice channels
  - Supervisory audio tone

- Set-up channels: There are 21 channels assigned each cell in a N = 4, 7, 12 cell reuse patterns.
- If set up channel antennas are Omni-directional, then each cell only needs one set up channel.
- This leaves many unused set-up channels.
- However, the set up channels of blocks A and B are adjacent to each other.
- In order to Avoid interference between block A and B , setup channels in the neighbourhood of channel 333(block A) and channel 334(block B) are preferably unused.

Channel assignments to travelling mobile units

- This situation always occur in the morning, when cars travel into the city, and at night, when the traffic pattern reverses.
- If the traffic density is uniform, the unsymmetrical mobile-unit antenna pattern does not affect the system operation much.
- However, when the traffic becomes heavier as more cars approach the city, the traffic pattern becomes nonuniform and the sites closest to 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 handing off calls to the sites away from the city.

Underlay-Overlay

- The traffic capacity at an omnidirectional cell or a directional cell can be increased by using the Underlay-Overlay arrangement.
- The underlay is the inner circle, and the overlay is Outer ring.
- The transmitted powers of the voice channels at the site are adjusted for these two areas.
- Then different voice frequencies are assigned to each area.

Underlay–Overlay

- One Overlay and One under lay are shown in fig.

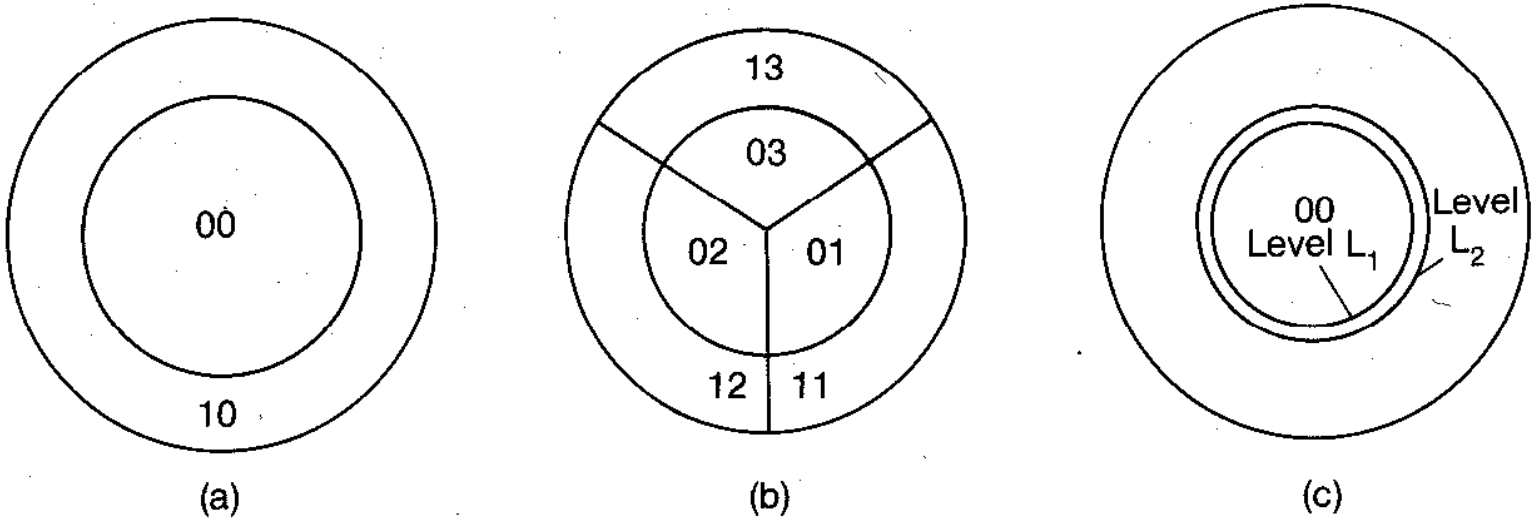


Figure 8.3 Underlaid-overlaid cell arrangements. (*a*) Underlay-overlay in omni-cell; (*b*) underlay-overlay in sectorized cells; (*c*) two-level handoff scheme.

- Because of the sectorization in a directional cell, the channel assignment has a different algorithm in six regions.

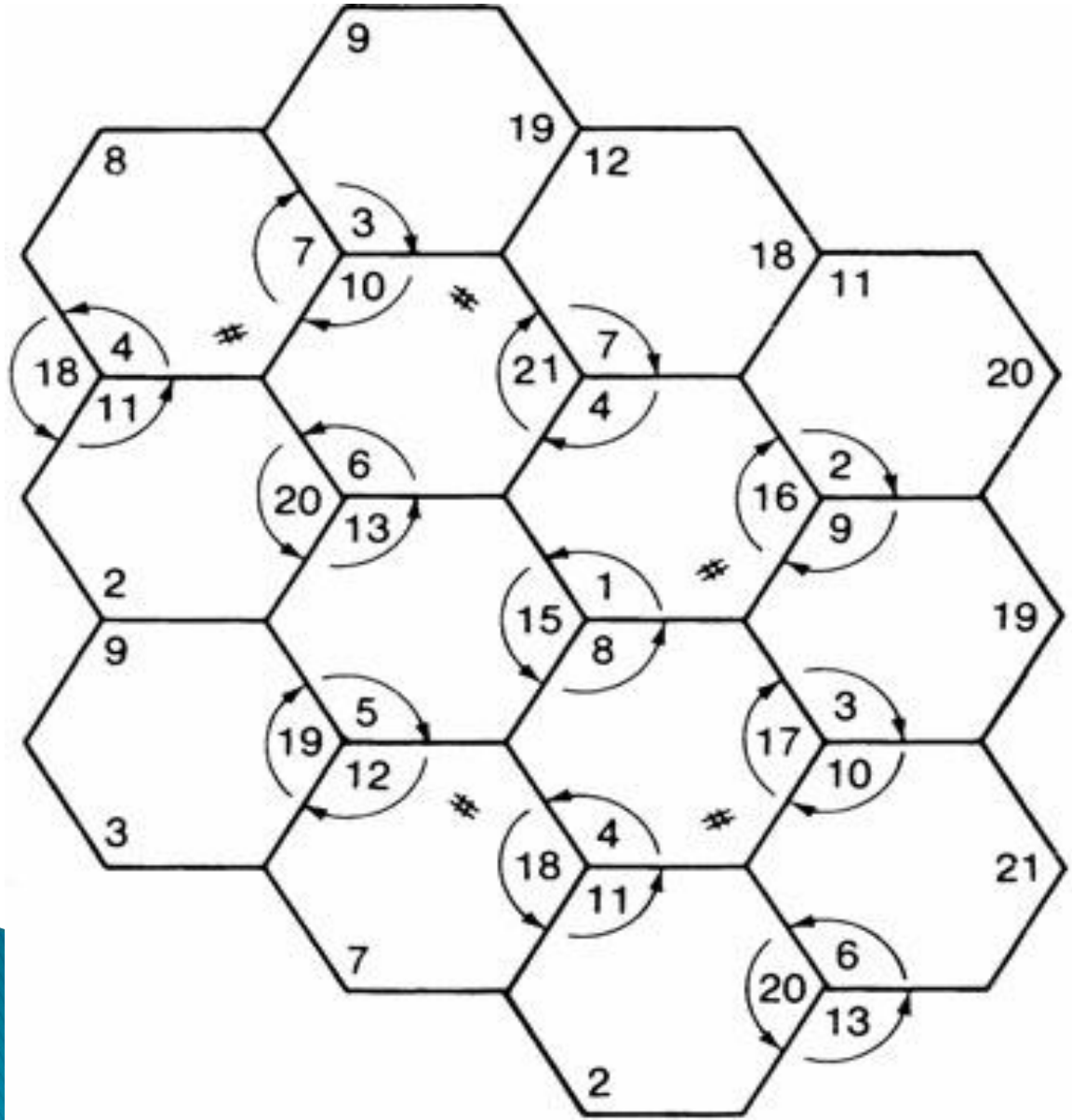
Frequency channel assignment

- We assign the frequencies by a set of channels or any part of a set or more than 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 interfering with adjacent co channel sectors or co channels.

Channel Sharing and Borrowing

- ***Channel Sharing.*** *Channel sharing is a short-term traffic-relief scheme.*
- *A* scheme used for a seven-cell three-face system is shown in Fig.
- There are 21 channel sets, with each set consisting of about 16 channels. Figure . shows the channel set numbers.
- When a cell needs more channels, the channels of another face at the same cell site can be shared to handle the short-term overload.

FIGURE .Channel-sharing algorithm.



possible interference area

Channel Sharing.

- Sharing always increases the trunking efficiency of channels.
- Since we cannot allow adjacent channels to share with the nominal channels in the same cell, channel sets 4 and 5 cannot both be shared with channel sets 12 and 18, as indicated by the grid mark.
- Many grid marks are indicated in Fig. for the same reason.
- However, the upper subset of set 4 can be shared with the lower subset of set 5 with no interference.

Channel Sharing.

- In channel-sharing systems, the channel combiner should be flexible in order to combine up to 32 channels in one face in real time.
- An alternative method is to install a standby antenna.

Channel Borrowing.

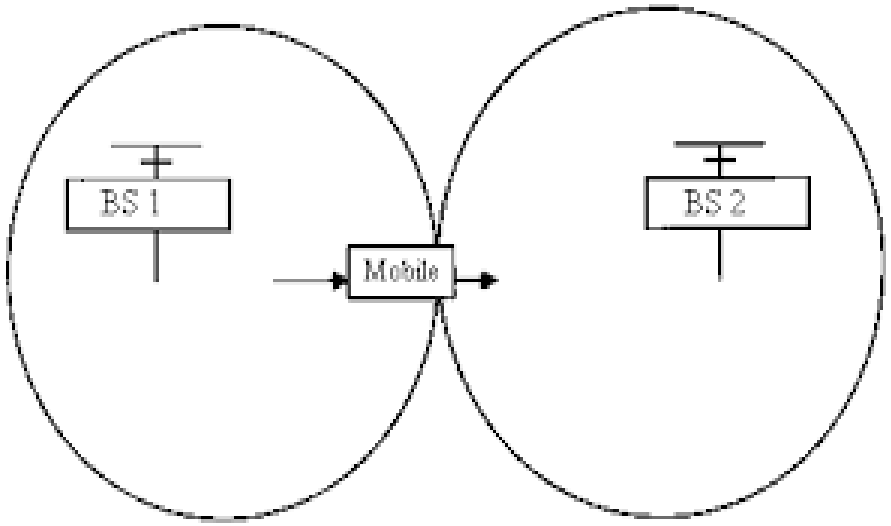
- *Channel borrowing is usually handled on a long-term* basis.
- The extent of borrowing more available channels from other cells depends on the traffic density in the area.
- Channel borrowing can be implemented from one cell-site face to another face at the same cell site.

Channel Borrowing.

- In addition, the central cell site can borrow channels from neighboring cells.
- The channel borrowing scheme is used primarily for slowly-growing systems.
- It is often helpful in delaying cell splitting in peak traffic areas.
- Since cell splitting is costly, it should be implemented only as a last resort.

Handoffs and dropped calls

- Handoff is a process of automatically changing frequencies as the mobile unit moves into a different frequency zone so that the conversation can be continued in a new frequency zone without redialing.



Handoffs Contd---------

- Why Handoffs?
- Handoff is needed in two situations where the cell site receives weak signals from the mobile unit:

1. At the cell boundary, say,-100dBm, which is the level for requesting a handoff.
2. When the mobile unit is reaching the signal strength holes(gaps) within the cell site as shown in below figure.

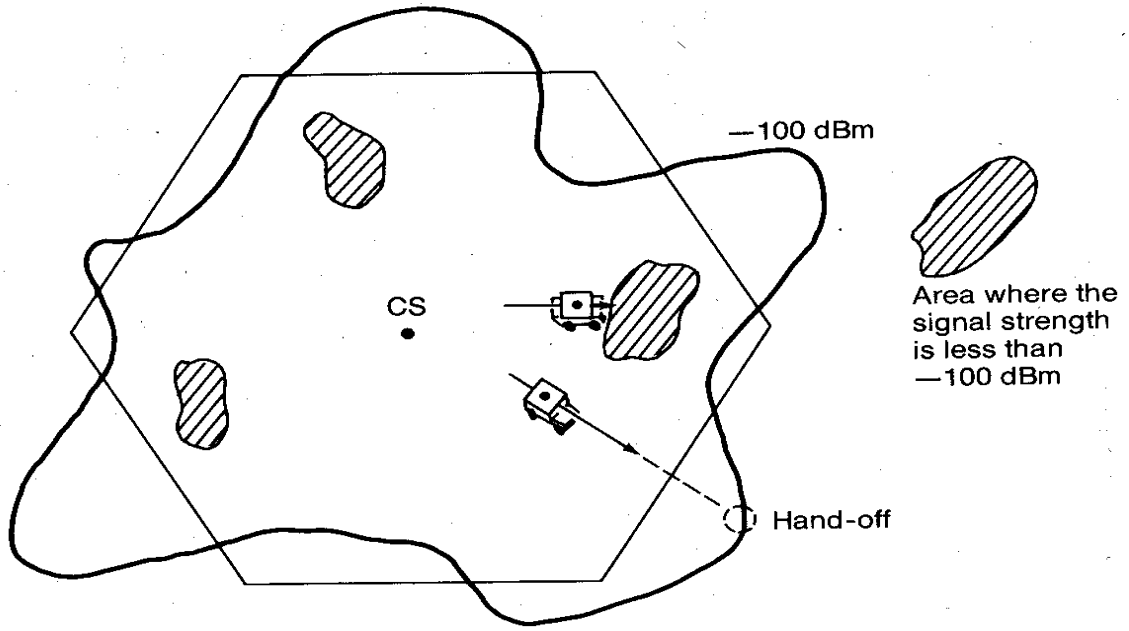


Figure 9.1 Occurrence of handoff.

- There are two types of handoff:

i) That based on signal strength

ii) That based on carrier to interference ratio.

- In type 1, the signal strength threshold level for handoff is -100dBm in noise-limited systems and -95 dBm in interference-limited systems.
- In type 2, the value of C/I at the cell boundary for handoff should be 18dB in order to have toll quality voice.
- The location receiver at each cell site measures all the signal strengths of all receivers at the cell site. The received signal strength(RSS) is given by

$$RSS = C + I$$

Where C is the carrier signal power and

I is the Interference.

Initiation of a Handoff

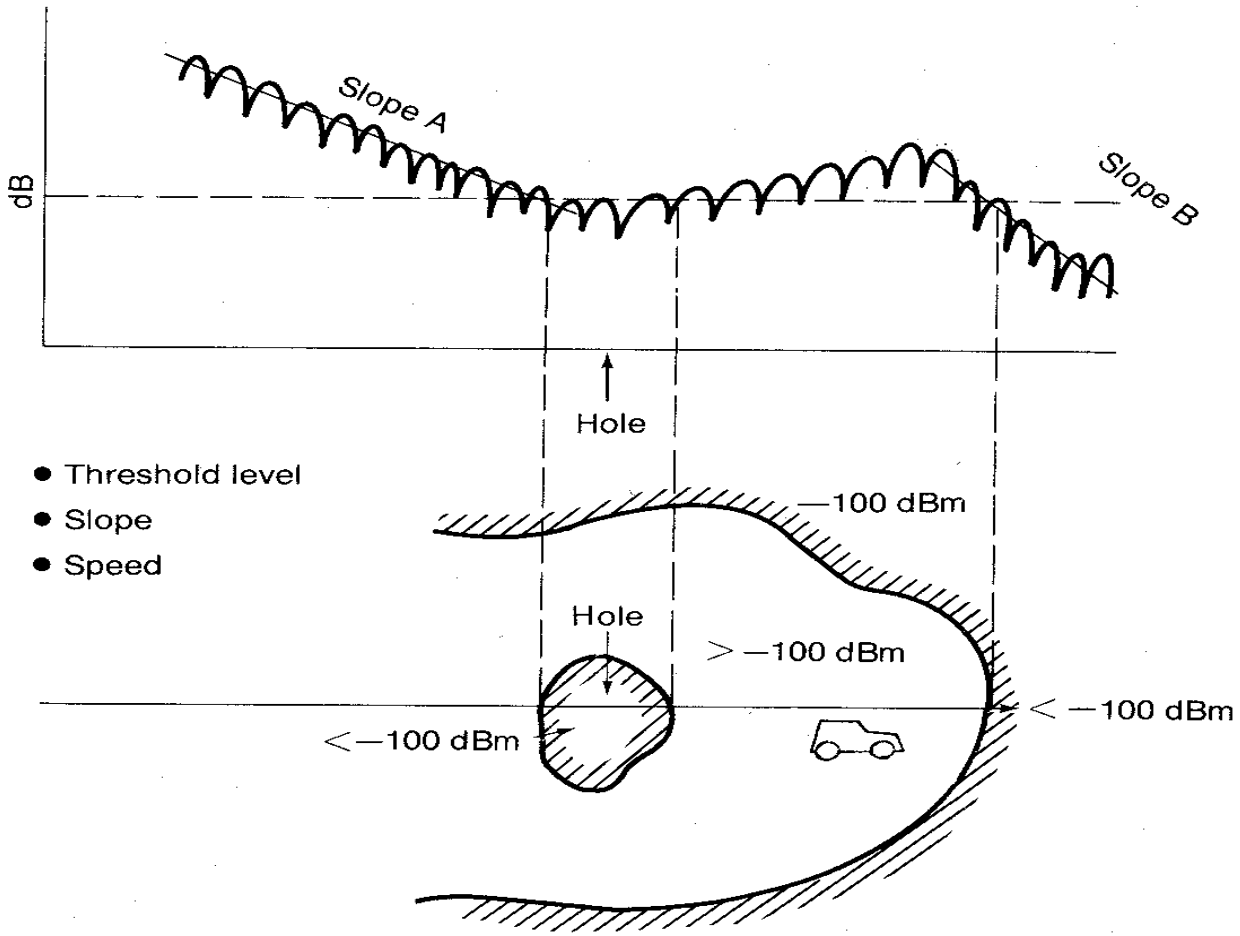
- At the cell site signal strength is always monitored from a reverse voice channel.
- When the signal strength reaches a level of handoff , then the cell site sends request to the mobile telephone switching office (MTSO) for a handoff on call.
- An intelligent decision can be made at the cell site weather the handoff should have to take place earlier or later.
- If an unnecessary handoff is requested, then the decision was made too earlier.
- If a failure handoff occurs, then a decision was made too late.

Initiation of a Handoff contd---

- The following approaches are used to make handoffs successful and to eliminate all unnecessary handoffs.
- Suppose that -100dBm is a threshold level at the cell boundary at which a handoff would be taken.
- In this scenario we must set up a new threshold level which is higher than -100dBm.
- Let it be -100dBm+Δ
- If Δ is large unnecessary handoff may take place and if it is too small time may not be enough for handoff, therefore Δ should be varied according to path loss slope and level crossing rate(LCR) of signal strength.
- If the value of Δ is 10dB, this mean that a level of

-90dBm is the new threshold level for requesting a handoff.

Initiation of a Handoff contd---



Initiation of a Handoff contd---

- There are two circumstances where handoffs are necessary but cannot be made:

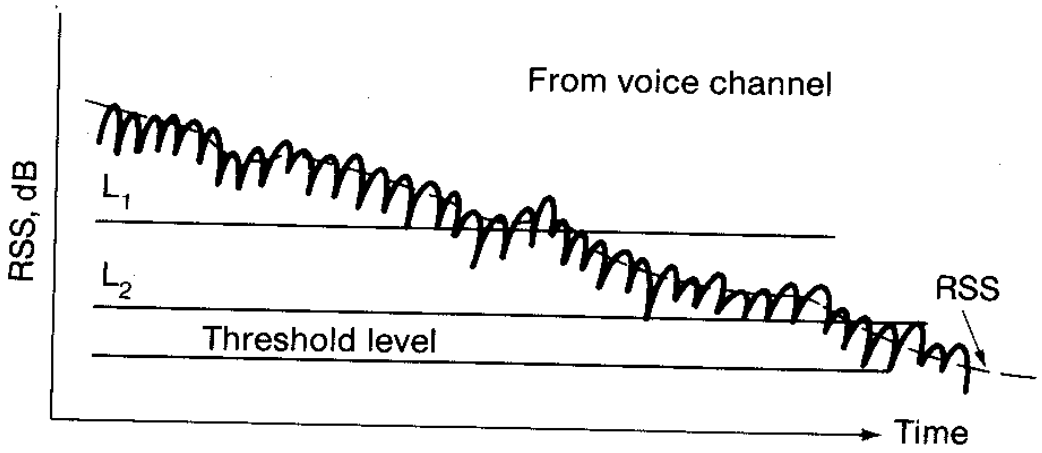
1.When the mobile unit is located at a signal strength hole with in a cell but not at the cell boundary as shown in above figure.

2. When the mobile unit approaches a cell boundary but no channels in the new cell are available.

- In case 1, the call must be kept in the old frequency channel until it is dropped as the result of an unaccepted signal level.
- In case 2, the new cell must reassign one of its frequency channels with in a reasonably short period or the call will be dropped.

Delaying a Handoff

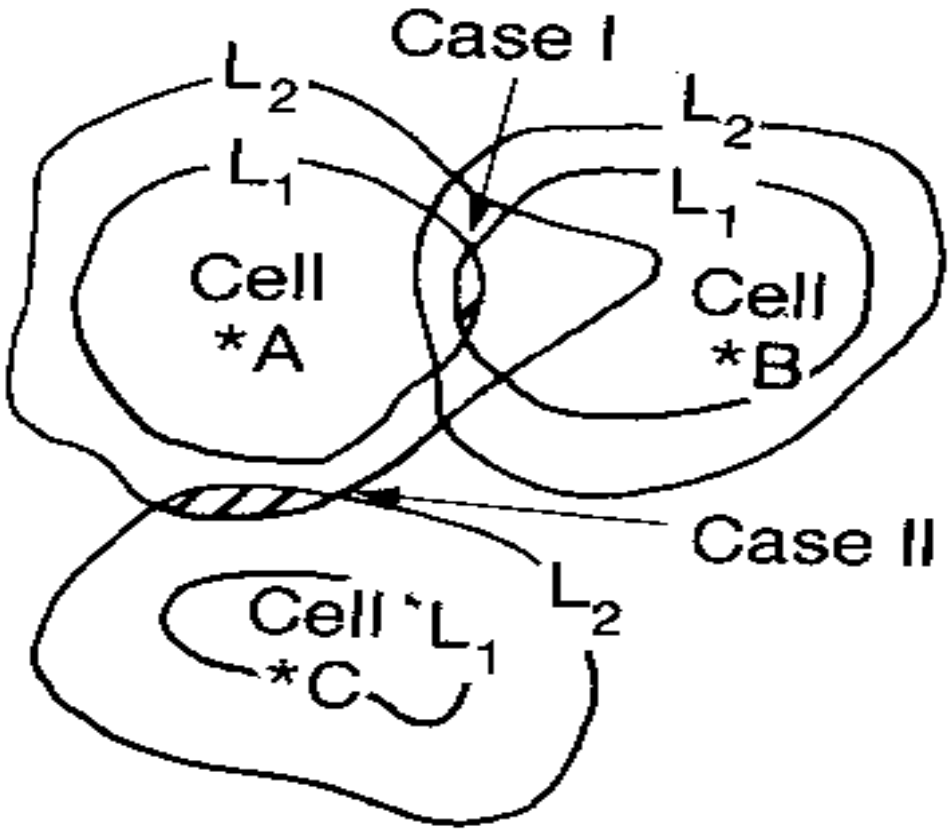
- In may cases , a two handoff level algorithm is used because to provide more opportunity for successful handoff.
- A handoff could be delayed if there is no available cell to take a call.
- A plot of signal strength with two request handoff levels and a threshold level is shown in figure.



Delaying a Handoff contd------

- The above plot is recorded on the channel received signal strength indicator(RSSI) which is installed at each channel receiver at the cell site.
- When the signal strength drops below the first handoff level a handoff request is initiated.
- If for some reasons the mobile unit is in a hole(a weak spot in a cell) or a neighboring cell is busy, the handoff will be requested periodically for every 5 seconds.
- At the first handoff level, the handoff takes place if the new signal is stronger(see case I in below figure)
- However when the second handoff level is reached, the call will be handed off with no condition (see case II in below figure)

Delaying a Handoff contd------



A two-level handoff scheme.

Delaying a Handoff contd------

- The MTSO always handles the handoff call first and the originating calls second.
- If no neighboring cells are available after the second handoff level, the call continues until the signal strength drops below the threshold level and then the call is dropped.
- Advantage of delayed handoff:
- When the mobile units are moving randomly and the terrain contour is uneven, the received signal strength at the mobile unit fluctuates up and down.
- In this situation if the mobile is in a hole for less than 5 seconds, the delay in handoff can even avoid the need for handoff.

Delaying a Handoff contd------

- The other advantage of having a two-level handoff algorithm is that it makes the handoff to occur in a proper location and eliminates possible interference in the system.
- In the above figure case I, the first level handoff occurs between cell A and B. If it is not possible, then we use the second level handoff.
- Case II also shows the second level handoff occurs between cell A and C. This is because the first level handoff cannot be implemented .

Forced Handoffs

- A forced handoff is defined as the handoff which would normally occur but is prevented from happening or, a handoff that should not occur but is forced to happen.
- This can be done by controlling a handoff or creating a handoff.
- Controlling a handoff:

1. The cell site can assign a low handoff threshold to keep a mobile unit in a cell longer or high handoff threshold level to request a handoff earlier.
2. The MTSO can also control a handoff by making a handoff earlier or later, after receiving a handoff request from a cell site.

Forced Handoffs Contd-------

- Creating a handoff:
- In this case, the cell site does not request a handoff but the MTSO finds some cells are too congested while others are not.MTSO can request cell sites to create early handoffs for those congested cells.
- In other words cell site has to follow the MTSO order and increase the handoff threshold to push the mobile units at the new boundary and to handoff earlier.

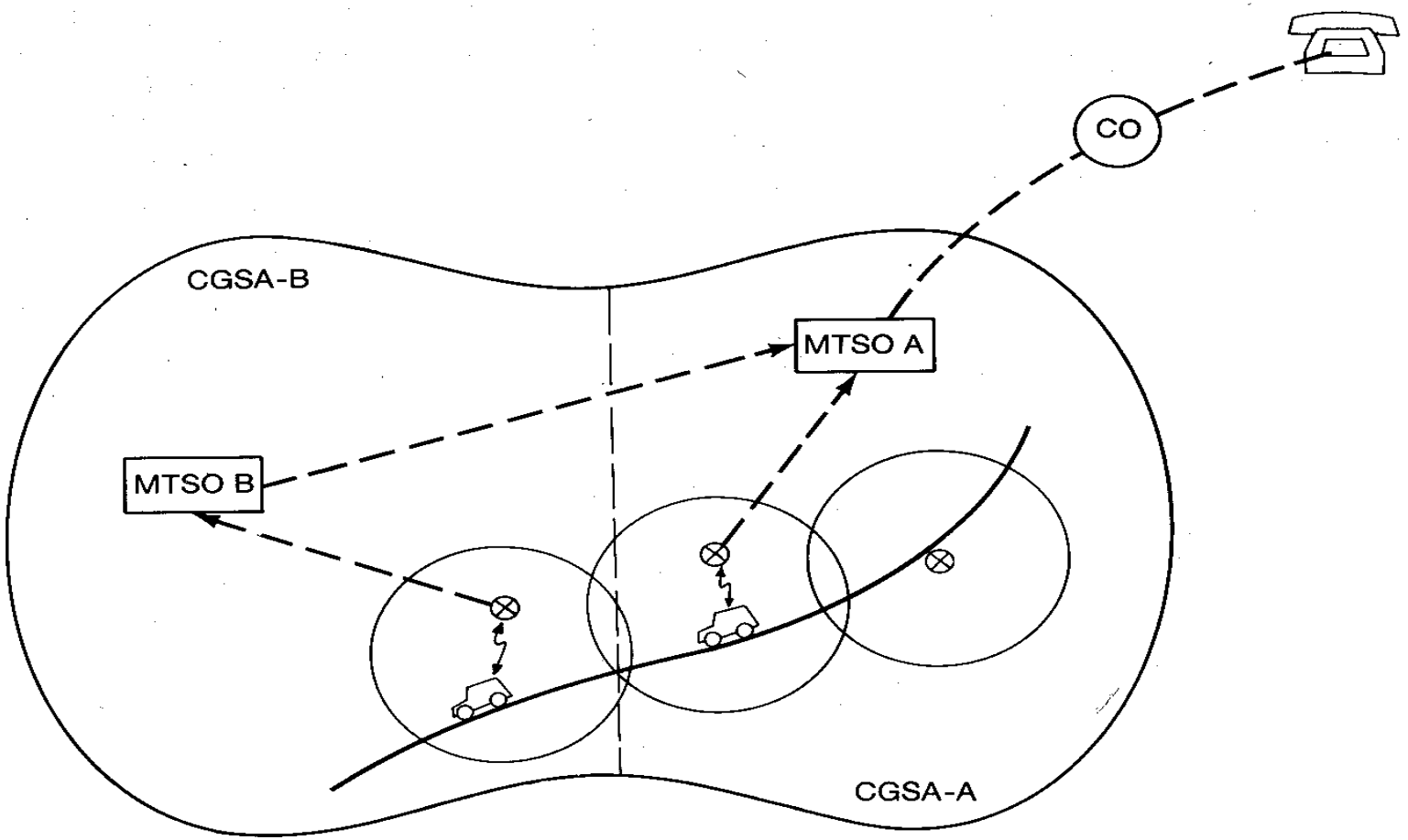
Mobile Assisted Handoff(MAHO)

- In normal Handoff procedure, the request for a handoff is based on the signal strength at the cell site from the reverse link.
- In the digital cellular system, the mobile receiver is capable of monitoring the signal strength of setup channels of neighboring cells while serving a call.
- For instance, in a TDMA system, one time slot is used for serving a call, the rest of the time slots can be used to monitor the signal strength of setup channels.
- When signal strength of its voice channel is weak, the mobile unit can request a handoff and indicate to the switching office that which neighboring cell is ready to handover the call.
- Now the switching office has two pieces if information, the signal strengths of both forward and reverse setup channels of neighboring cell
- The switching office, therefore, has more intelligent information to choose proper neighboring cell to handoff the call.

Intersystem Handoff

- Some times call may be initiated in one cellular system controlled by one MTSO and enter another system controlled by another MTSO before terminating.
- Inter system handoff can be defined as a call handoff that can be transferred from one system to second system so that the call can be continued while the mobile unit enters the second system.
- The software in the MTSO must be modified to apply this situation.

Intersystem Handoff Contd----



Intersystem handoffs.

Intersystem Handoff contd----

- Consider the example shown in shown in above figure.
- The car travels on a highway and the driver originates the call in system A
- Car leaves cell site A of system A and enters cell site B of system B
- When mobile unit signal becomes weak in cell site A, MTSO A searches for a neighboring cell site in the system and if it does not find any one, MTSO A sends a handoff request to MTSO B which makes a complete handoff during the call conversation.

Dropped call rate

- " The call is established " means the call is setup completely by the setup channel
- If there is a possibility of a call drop due to no available voice channels, this is counted as a 'blocked call' not a dropped call.
- If there is a possibility that call will drop due to the poor signal of assigned voice channel, that is considered as dropped call.
- If call is terminated before it is properly terminated may be due to:
  - Subscriber unit not functioning properly.
  - Operating in vehicle
  - User not having knowledge of best reception of signal.

- One of major reason of dropped calls is improper handoff, a proper timely handoff is one of the procedures to reduce dropped calls.
- During handoff between two cells due to an imbalance of traffic between the two cell site areas, it cannot accept the additional traffic of the call then there is a chance of call dropping. The dropping probability is defined as the percentage of handoff attempts that are denied because of insufficient resources in the cell into which the mobile is moving.

- The number of dropped calls in cellular system is dependent on the dropped call rate. The dropped call rate is dependent on the following factors:

- The channel capacity
- Level of traffic in the system (highly populated areas such as metro cities and business area save more chances of handoffs and so the dropped call rate increases).
- Voice quality
- Probability that the signal below the receiver threshold (Δ)
- Probability that the signal below the specified co-channel interference level (*m)*

- **Channel capacity:**
- Channel capacity is directly proportional to bandwidth of the system. If bandwidth is more, then more number of channels (users) can be allotted.
- With the increase in channels, adjacent channel interference also increases and so signal-to-interference ratio decreases.
- This leads to poor signal quality and increased dropped call rate.
- There is a relation between channel capacity, the number of voice channels, and the signal to-noise ratio as given below:
- The radio capacity

$$RC = \frac{N}{\sqrt{2/3(S/I)}}$$

where N = total number of channels
S/I = required SIR ratio for designing a system.

- **Level of traffi c in the system:**
- Traffic intensity is the measurement of traffic generated by a user during the busy hour (BH).
- The total number of voice calls originated or terminated in a mobile during the BH is called voice traffic arrival rate and voice traffic is generally represented by the unit called Erlang.
- Erlang is defined as a voice call of one hour duration. Each voice call is held for certain duration. The average duration of all voice calls is called holding time of a call. Similarly, departure rate can be considered as "1 / *T*".
- If *R represents the arrival rate of voice calls during a BH (call/s)and T represents average* holding time of a call (in seconds), the total BH voice traffic is given by *RT. Then,*

$$\text{the total traffic (in Erlangs)} = \frac{RT}{3600}\text{Erlang.}$$

Receiver threshold (δ) and co-channel interference level (μ)

If we consider a whole cellular system, the general formula for dropped call rate *D will be given as*

$$D = 1 - \left[\sum_{n=0}^{N} a_n X^n \right] = \sum_{n=0}^{N} a_n D_n$$

$$D_n = 1 - X^n$$

where

D_n = the probability of a dropped call when the call has gone through n handoffs and

$$X = (1 - \delta)\,(1 - \mu)\,(1 - \theta\zeta)\,(1 - \beta)^2 \qquad (18.14)$$

δ = probability that the signal is below the specified receiver threshold (in a noise limited case)

μ = probability that the signal is below the specified co-channel interference level (in interference-limited case)

ζ = probability that no channel is available for handoff when moving into a new cell

θ = probability that the call will return to the original cell

β = probability of blocking circuits between BSC and MSC during handoff

a_n = the weighted value for those calls having "n" handoffs, and $\sum_{n=0}^{N} a_n = 1$

N = the highest number of handoffs for those calls

In general, the values of ζ, θ, and β are assumed to be very small and can be neglected. Hence, we can take

$$X = (1 - \delta)\,(1 - \mu) \qquad (18.15)$$

Now we are able to deduce the expressions of dropped call rate for the following two cases:

Now we are able to deduce the expressions of dropped call rate for the following two cases:

1. Noise-limited system, $\mu \to 0$.
2. Interference-limited system, $\delta \to 0$.

Noise-limited system, $\mu \to 0$

Here, we are considering only noise limited system, so the effect of receiver threshold signal can be considered and also assumed that there will not be any co-channel interference. In such a case, since $\mu \to 0$ the expression for dropped call rate is

$$D = \sum_{n=0}^{N} a_n D_n = \sum_{n=0}^{N} a_n [1 - (1 - \delta)^n] \tag{18.16}$$

Interference-limited system, $\delta \to 0$

Here, we consider only interference-limited system, so the effect of co-channel interference can be considered and also assumed that there will not be any kind of noise which is introducing in the system. In such a case, since $\delta \to 0$ and the expression for dropped call rate is

$$D = \sum_{n=0}^{N} a_n D_n = \sum_{n=0}^{N} a_n [1 - (1 - \mu)^n] \tag{18.17}$$