Παρουσιάσεις για το Μάθημα Ασύρματων και Κινητών Τηλεπικοινωνιών του ΔΜΠΣ στο ΕΚΠΑ

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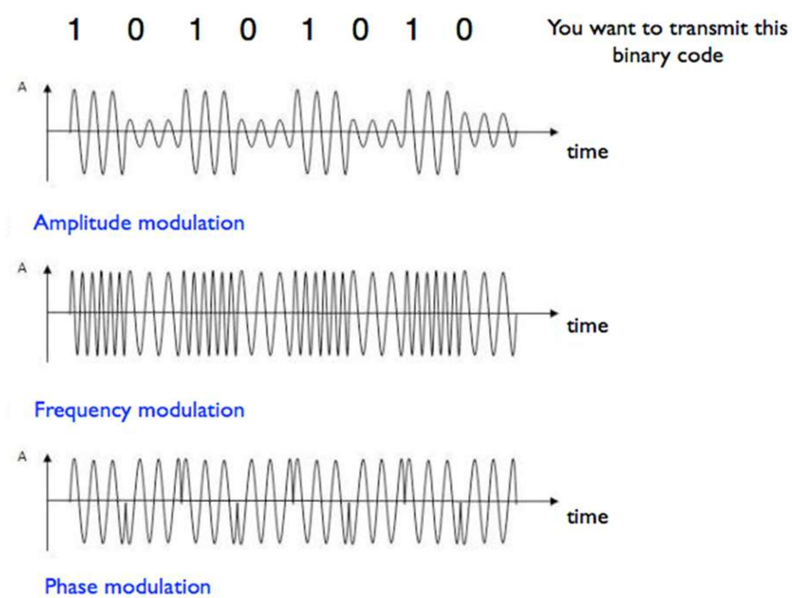
Wireless Transmission

Wireless Transmission

- **Communication (i.e. transmission of a message) over wireless media necessitates the employment of advanced signal processing techniques to combat the effects of path loss, fading, multipath and Doppler shift and thus, improve radio link performance**
  - **Modulation**
  - **Equalization: it compensates for the spread of pulses in time (Intersymbol Interference)**
  - **Diversity (in space, frequency or time)**
  - **Channel coding: it combats fading by adding redundant bits in the Tx messages**
- **These techniques are appropriately applied at the Transmitter and de-applied at the Receiver to yield the desired input signal**

Modulation

- Modulation is the process of encoding information from a message source in a manner suitable for transmission
- It generally involves the translation of a "baseband" signal (source) to a "bandpass" signal at much higher frequencies
- Modulation may be done by varying the amplitude, phase or frequency of a high frequency carrier in accordance with the amplitude of the input signal
- Modulation schemes may be Analog (ex. amplitude, frequency) or Digital



Digital Modulation

- In digital wireless communication systems, the input signal is represented by a time sequence of symbols (or pulses), where each symbol may take **m** different finite states
- Each symbol represents **n** bits of information

$$m = 2^n \Leftrightarrow n = \log_2 m \; bits / symbol$$

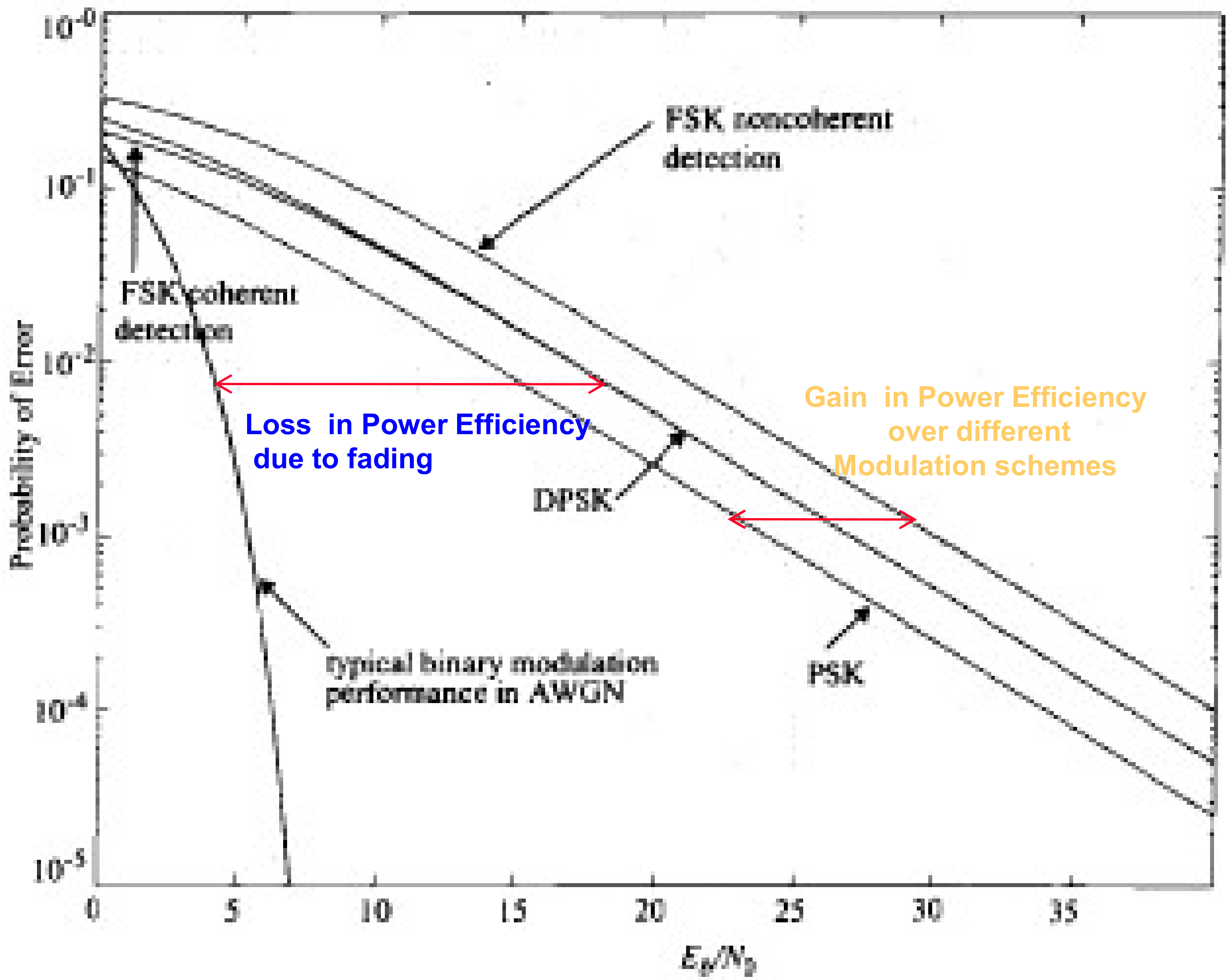
- The ideal modulation scheme would
  - provide low bit error rates at low received SNR,
  - Perform well in multipath and fading conditions
  - Occupy a minimum of bandwidth
  - Would be easy and cost-effective to implement

Example	
n = 3, m = 8	
000	001
010	011
100	101
110	111

Digital Modulation – cont'd

- **The appropriate modulation scheme is decided on a per-case basis, according to its performance and the application under consideration**
- **Modulation performance may be measured in terms of:**
  - — **Power efficiency, or**
  - — **Bandwidth efficiency**
- **<u>Power (or energy) Efficiency</u> is usually described as the ratio of the Signal Energy per Bit to Noise Power Spectral Density required at the Rx for E_b/N_0 a certain Probability of error (say 0,001, i.e., 1 error bit every 1000 transmitted)**

Modulation Performance in Fading and Multipath



An EbNo curve
(Prob of Error vs Eb/No)
characterizes radio link performance

Digital Modulation – cont'd

- **<u>Bandwidth Efficiency</u> describes the ability of a modulation scheme to accommodate data within a limited bandwidth. It reflects how efficiently the allocated bandwidth is utilized**

$$n_B = \frac{R}{B}\, bps / Hz$$

  - **R is the data rate in bits per sec.**
  - **B is the bandwidth occupied by the modulated signal**

- **<u>Maximum Achievable</u> bandwidth efficiency (Shannon's Theorem)**

$$n_{B\max} = \frac{C}{B} = \log_2(1 + \frac{S}{N})$$

  - **C is the channel capacity,**
  - **S/N is the signal-to-noise ratio (SNR)**

Digital Modulation – cont'd

Example 3.1:

- **A communication link is characterized by:**
  - **SNR 20dB (for acceptable service quality)**
  - **RF bandwidth 30 KHz**
- **Then, the max. theoretical data rate that can be supported is:**

$$C = B\log_2(1+\frac{S}{N}) = 199{,}75\ kbps$$

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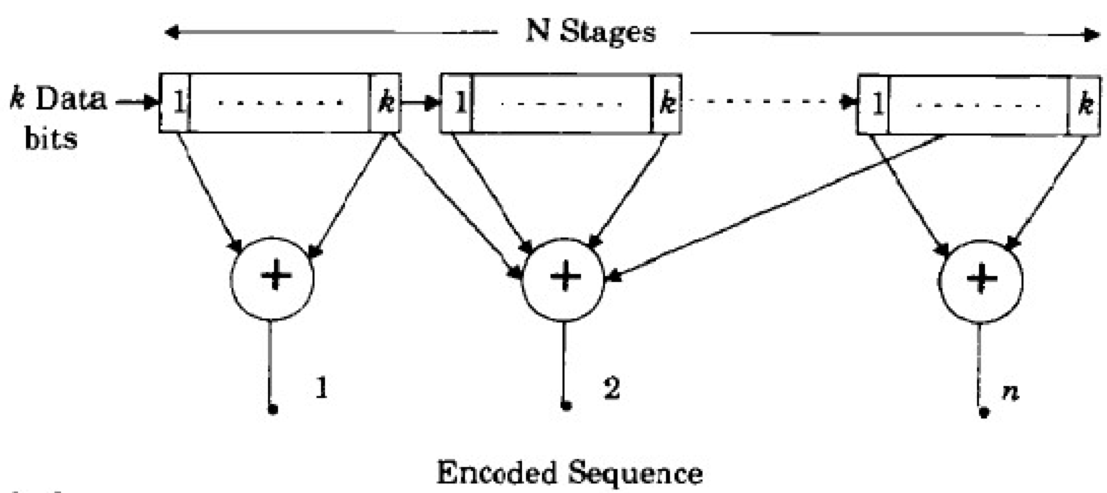
Channel Coding

- The idea behind:
  - Additional bits are added to the original message, introducing redundancies to the system
- There are mainly two types of codes, able of:
  - Detecting only, or
  - Correcting

  the bits in error.
- Coding Gain is the difference in Eb/No required between a coded and uncoded system to achieve the same link performance (BER)

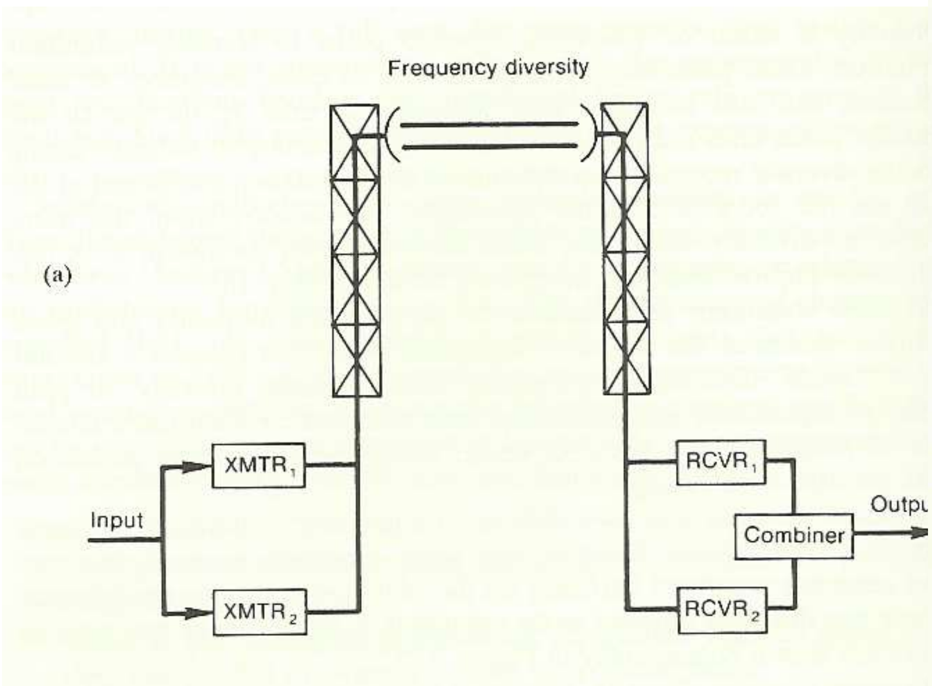


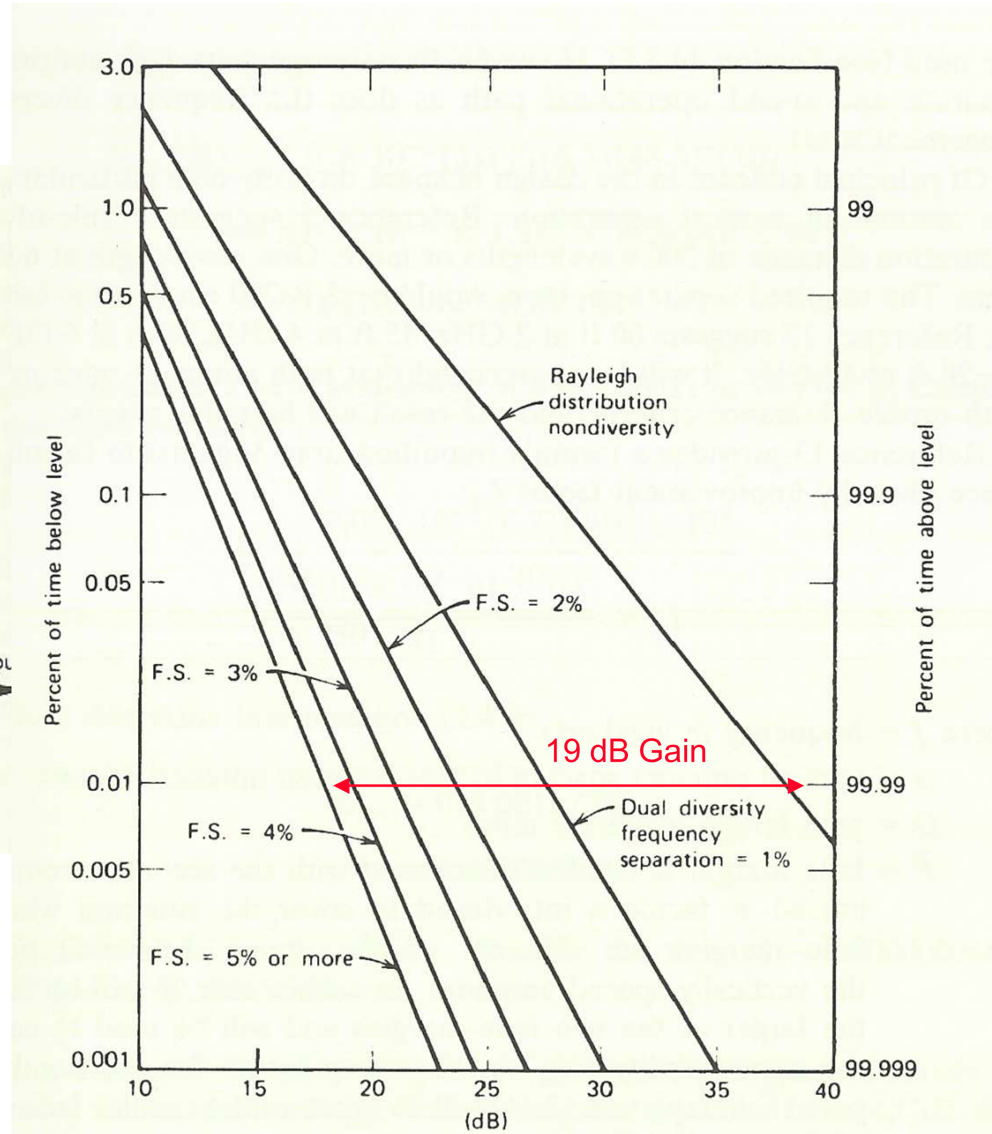
Typical Convolutional Encoder

Diversity techniques

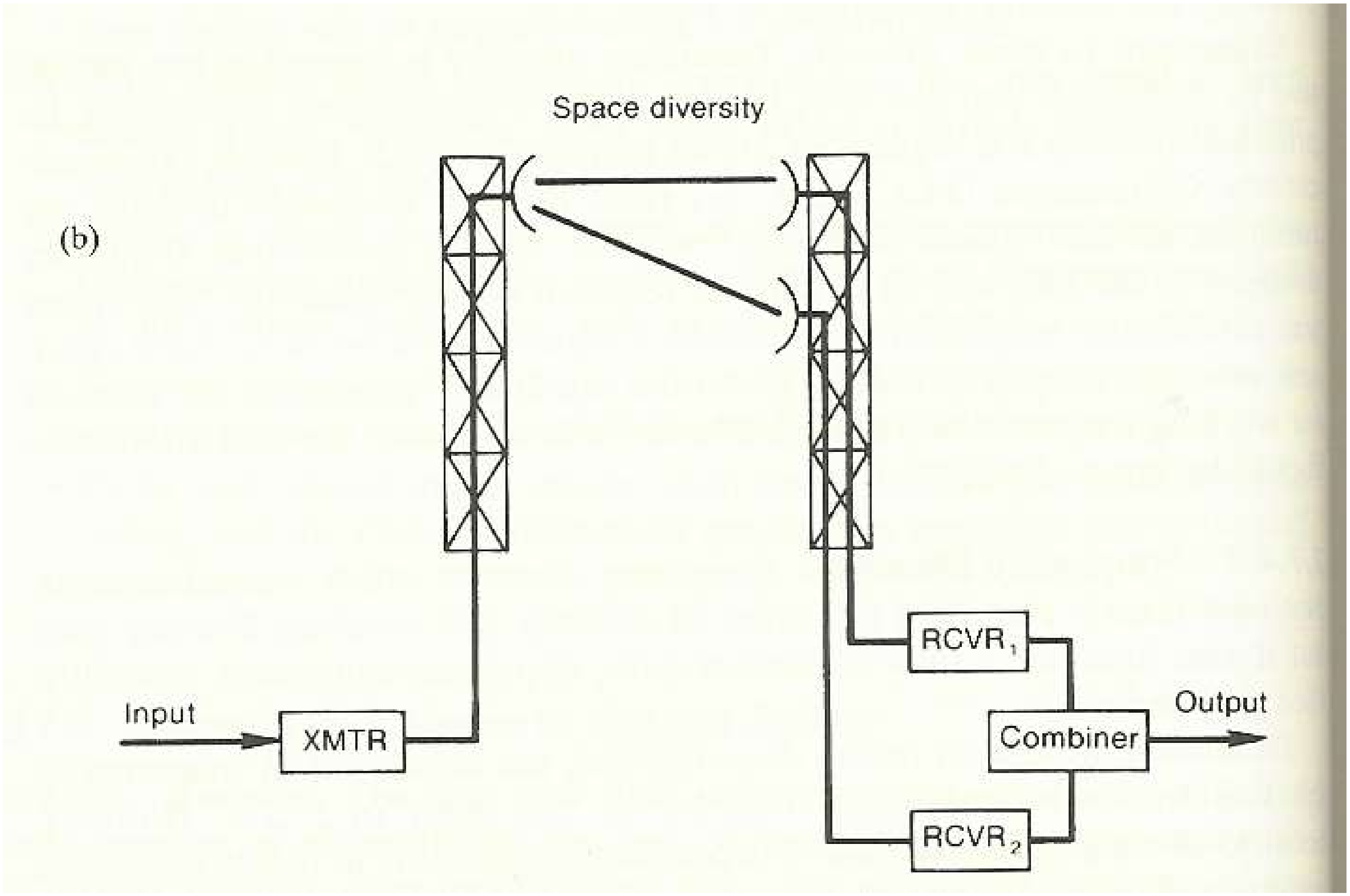
- Diversity exploits the random nature of radio propagation by finding independent (or at least highly uncorrelated) signal paths
- The idea behind:
  - If one radio path undergoes a deep fade, then another independent path may have a strong signal
  - Consider all independent paths arriving at Rx and select those with strong signals
  - Overall signal may be improved by 20-30dB
- Most popular techniques:
  - Space diversity (i.e. using separate antennas)
    - Micro diversity, using separate antennas (space diversity), applied to small-scale fading
    - Macro diversity using more than one Bs's, applied to large-scale fading
  - Polarization diversity
  - Frequency diversity
  - Time diversity

Frequency Diversity to mitigate fading

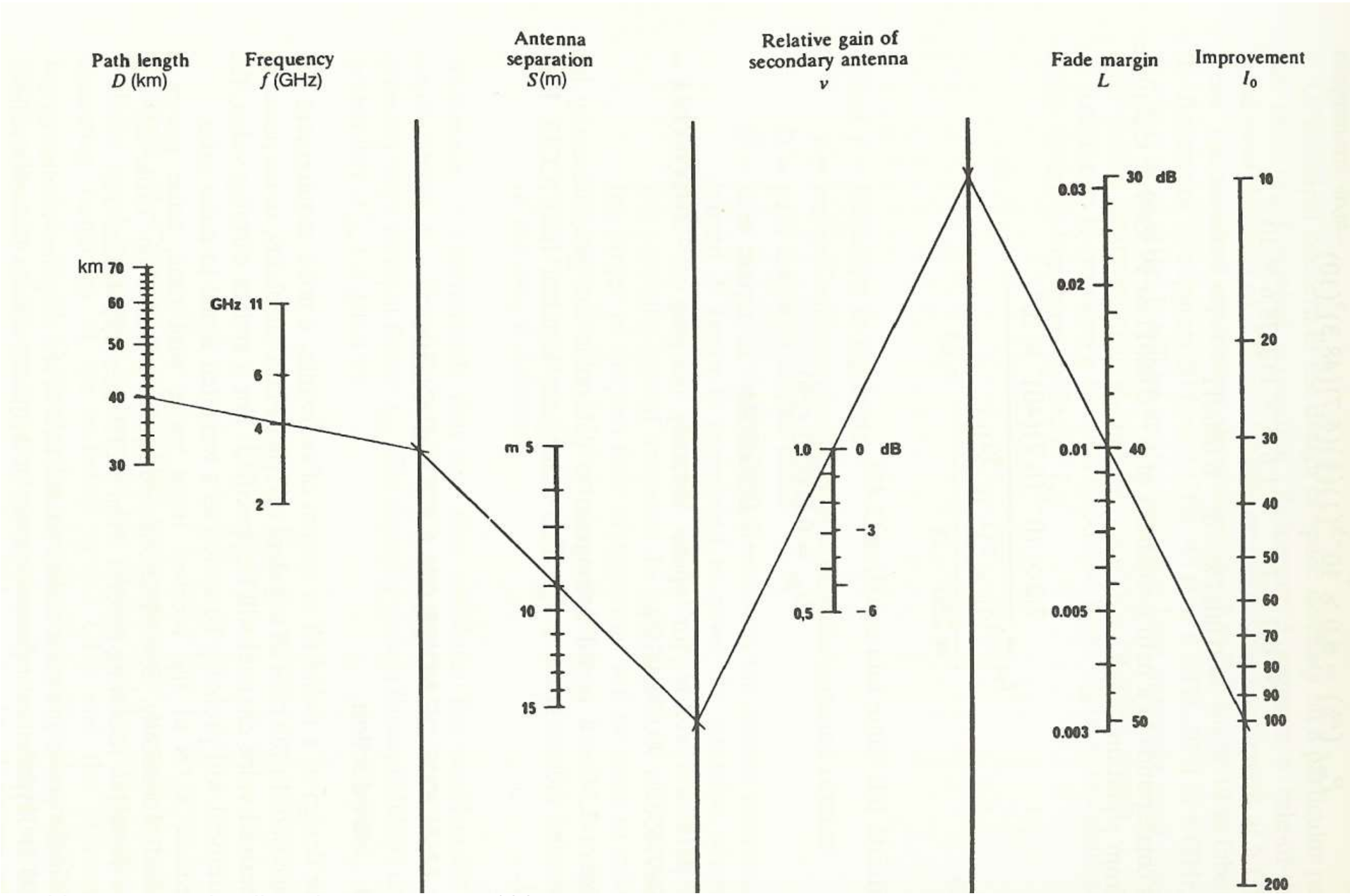




Spatial Diversity to mitigate fading



Spatial Diversity to mitigate fading, cont'd

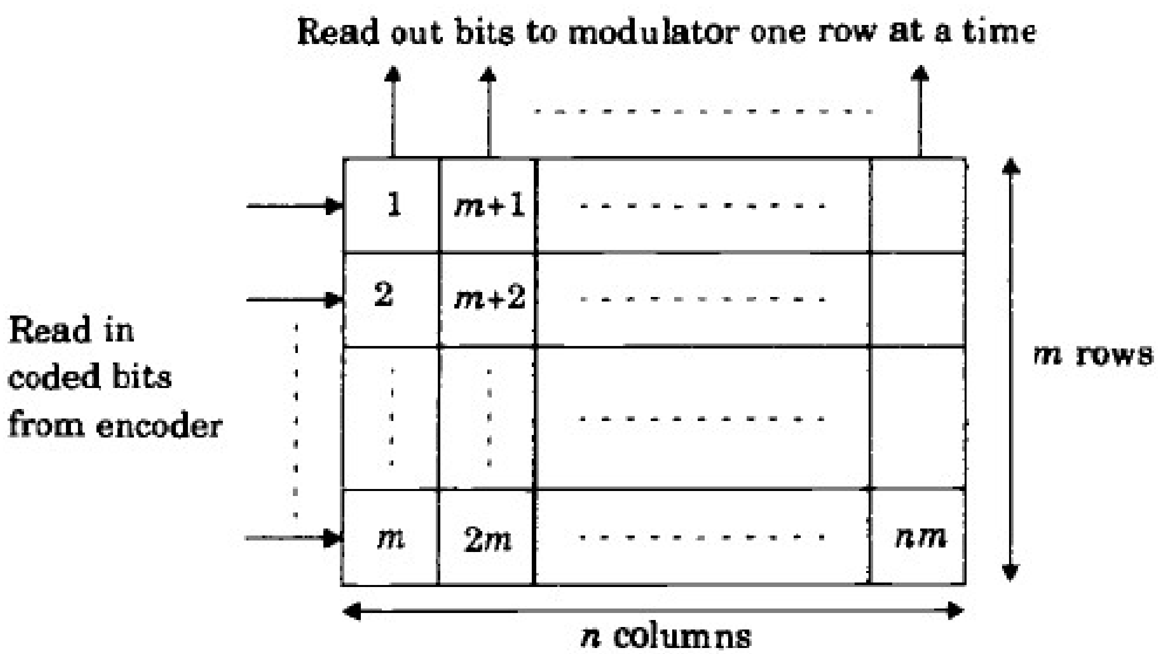


In this example, the diversity outage gets 100 times less than that of the non-diversity system

Diversity Outage = Non-Div. Outage / Improvement Factor

Time Diversity - Interleaving

- The idea behind:
  - Important successive bits are spread in time so that if a deep fade or noise burst occurs, then the important bits from a block of source data are not corrupted at the same time
  - The received message block cannot be fully decoded until all bits of the block arrive at the Rx and de-interleaved, thus leading to a delay, equal to the size of the block (n*m)



In speech transmission,
delays should not exceed 40ms!!!

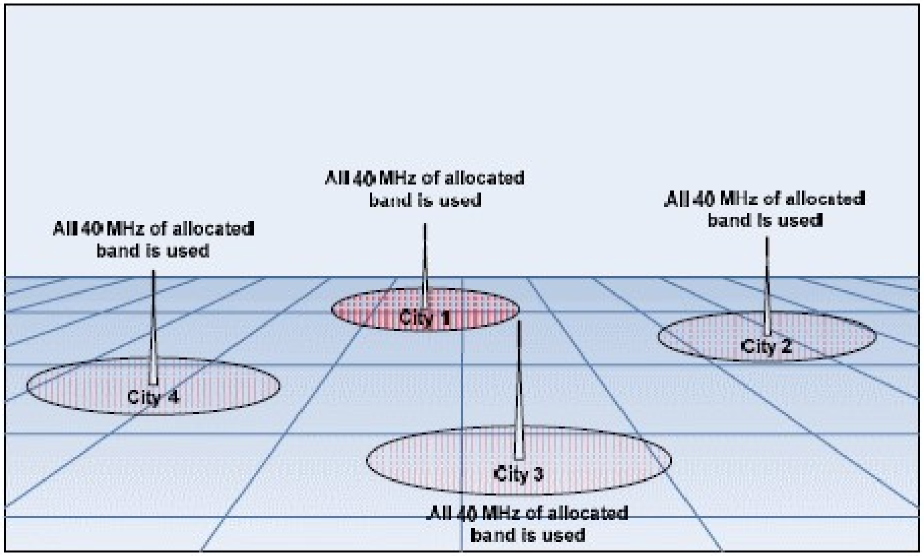
Cellular Systems

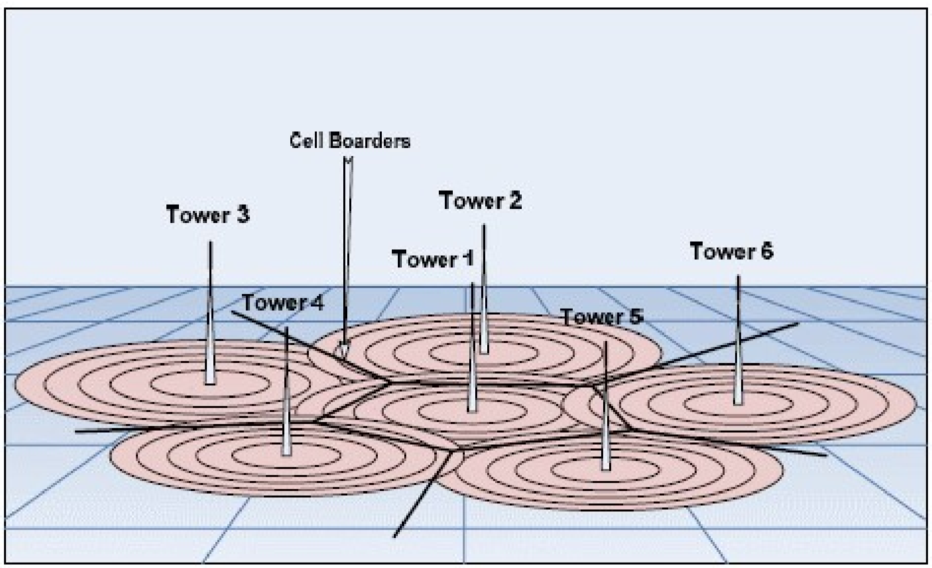
The Cellular Concept

- **Radio communication is achieved through assigning a part of the frequency spectrum (channel) to every user**
- **For a given bandwidth, there is a max number of users who can be served (Shannon's Theorem), leading to low system capacity.**
- **On the other hand, radio signal propagation characteristics, necessitate the use of high Tx powers as the distance between the BS and the users increases, leading to low system coverage**
- **Problem: Use of one Tx (BS) leads to low coverage and capacity**
- **Solution:**
  - **Use multiple BS's, each having a specified set of channels and repeat this layout throughout the target coverage area, thus achieving a Cellular network structure**
  - **However, in this case careful frequency assignment should be performed to minimize co-channel and adjacent channel interference**

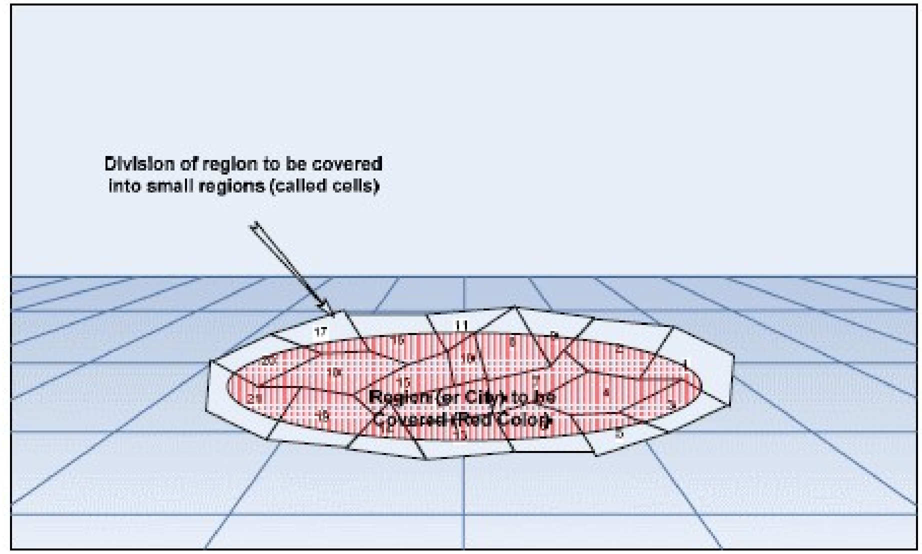
The Cellular Concept, cont'd

Older Systems

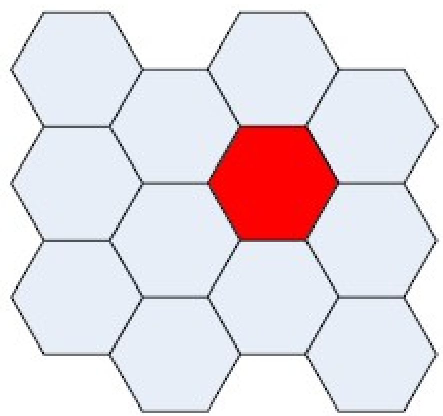




Present Day Systems



Hexagon-structured layouts are used to <u>model ideal</u> cellular networks



The Concept of Frequency Reuse

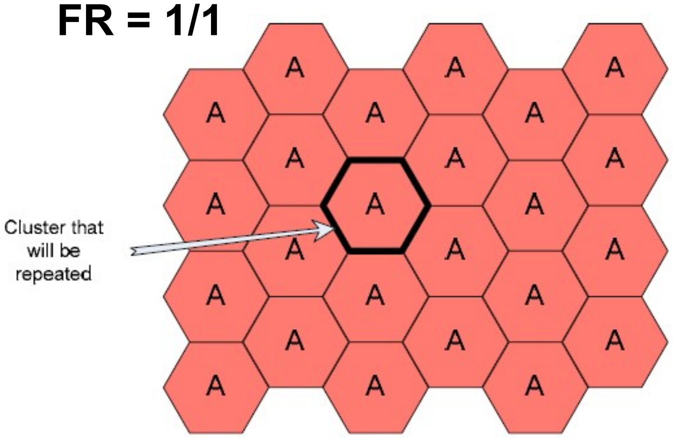
- **Design a cluster of N cells,**
- **Each cell in the cluster gets k channels**
- **The total available bandwidth is then S = k*N**
- **Replicate the cluster of N sells, so many times (say M) to cover the full target area**

- **Then, system Capacity C is:** $$C = M * S = M * k * N$$

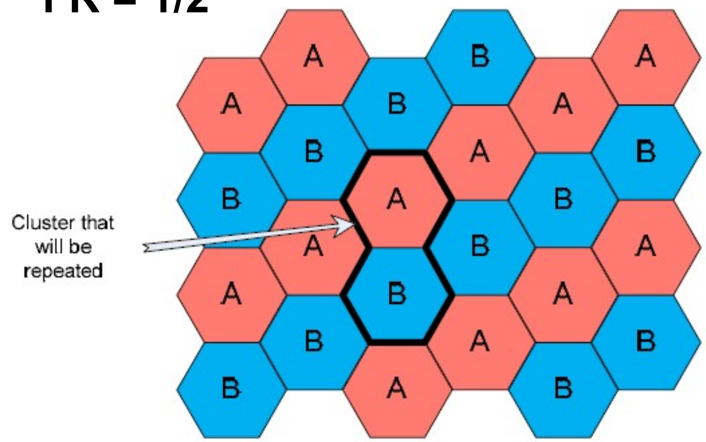
- **Frequency Reuse = 1/N**

Frequency Reuse (FR) Schemes

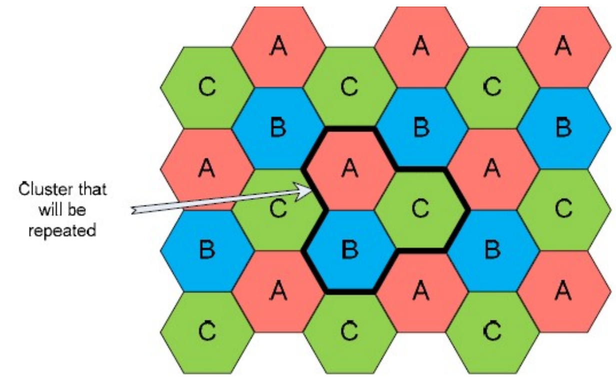
FR = 1/1



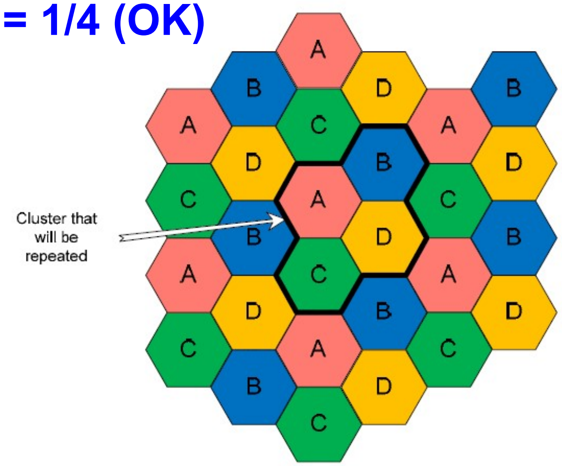
FR = 1/2



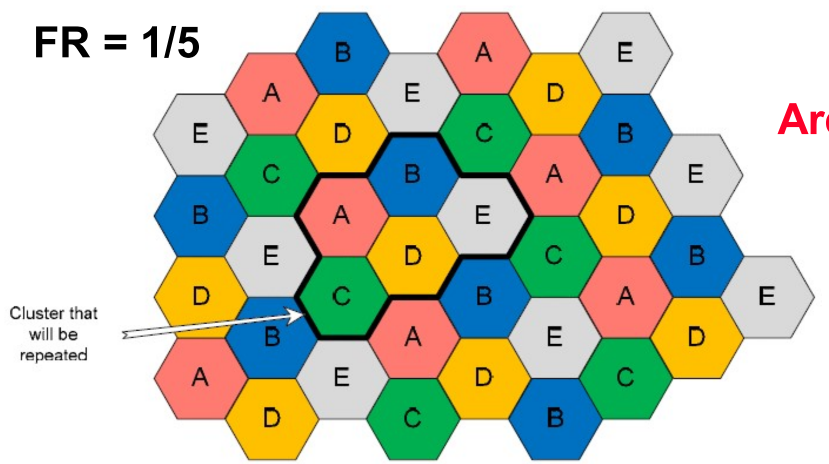
FR = 1/3 (OK)



FR = 1/4 (OK)



FR = 1/5



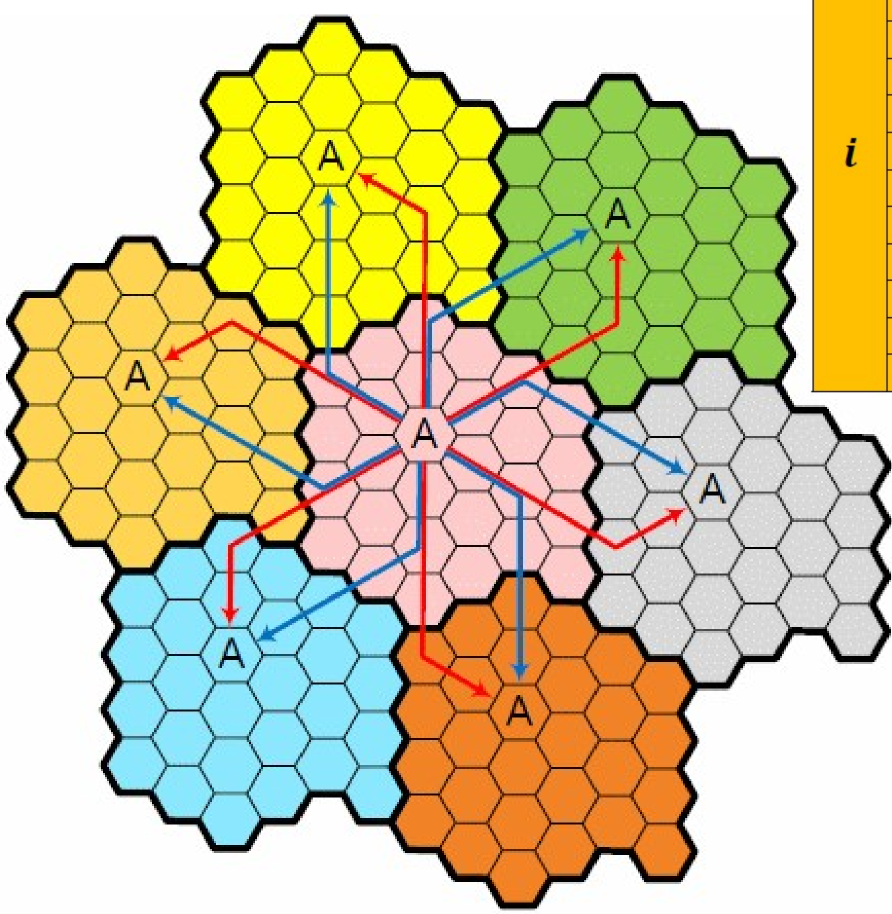
Are all Frequency Reuse schemes valid?

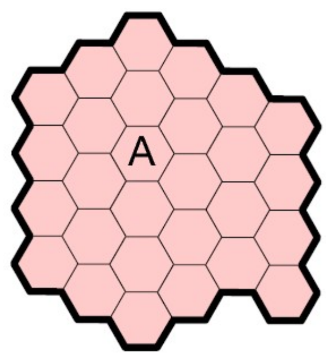
Valid Cluster sizes

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

Example:
Let N = 28, (i=2, j=4)

N		j												
		0	1	2	3	4	5	6	7	8	9	10	11	12
	0			4	9	16	25	36	49	64	81	100	121	144
	1		3	7	13	21	31	43	57	73	91	111	133	157
	2			12	19	28	39	52	67	84	103	124	147	172
	3				27	37	49	63	79	97	117	139	163	189
	4					48	61	76	93	112	133	156	181	208
	5						75	91	109	129	151	175	201	229
i	6							108	127	148	171	196	223	252
	7								147	169	193	219	247	277
	8									192	217	244	273	304
	9										243	271	301	333
	10											300	331	364
	11												363	397
	12													432





Nearest co-channel cells:
- **From original cell,**
  - **Along j cells and then**
  - **i cells counter-clockwise, or**
  - **Along i cells and then**
  - **j cells clockwise**

Interference and System Capacity

- **Co-channel interference:** **caused by other signals using the same channel**
- **Adjacent-channel interference:** **caused by signals using adjacent channels**
  - **Co-channel Interference becomes a function of the cell radius, R and the distance from the closest co-channel cell, D**
  - **Q is the co-channel reuse ratio**

$$Q = \frac{D}{R} = \sqrt{3N}$$

  - **Signal to Interference ratio:**

$$S/I = \frac{S}{\sum_{i=1}^{i_0} I_i} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} \approx \frac{Q^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

Path loss exponent

Power of desired signal
From desired cell

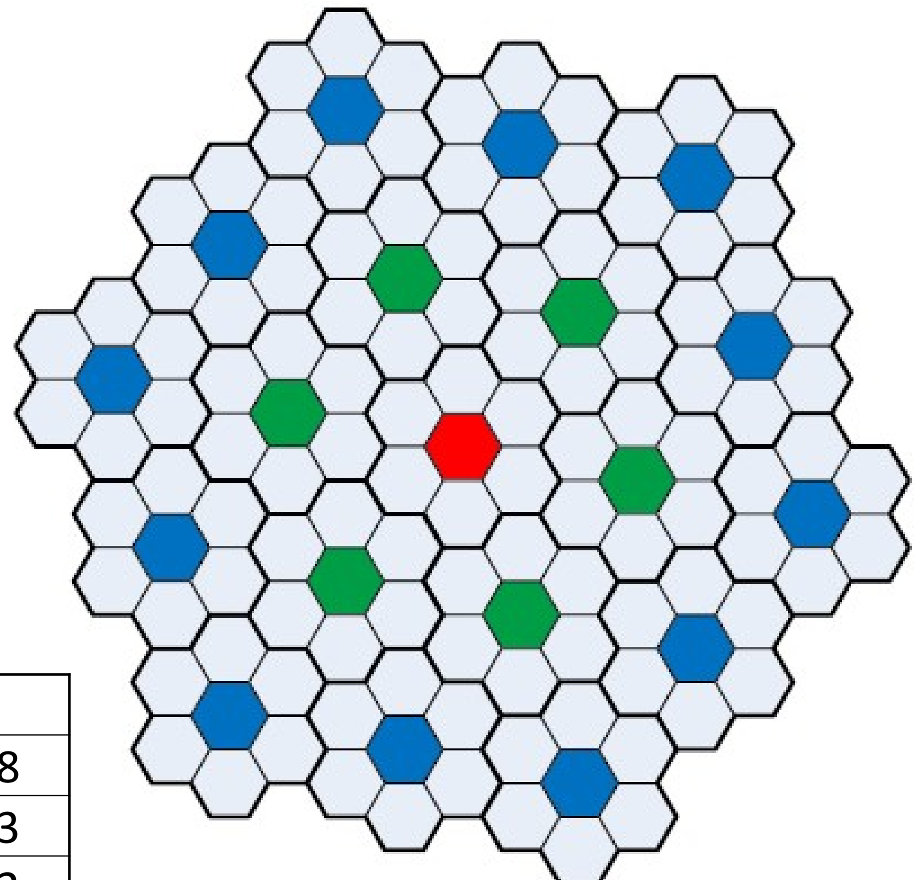
Number of
interfering co-channels

Interference from
i-th co-channel cell

Co-channel Interference

Usually:

- **1^{st} tier cells** **contribute most of the co-channel interference relative to 2^{nd} tier cells**



$$\frac{I_{Tier2}}{I_{Tier1}} \approx \frac{1}{2^n} + \frac{1}{1{,}73^n}$$

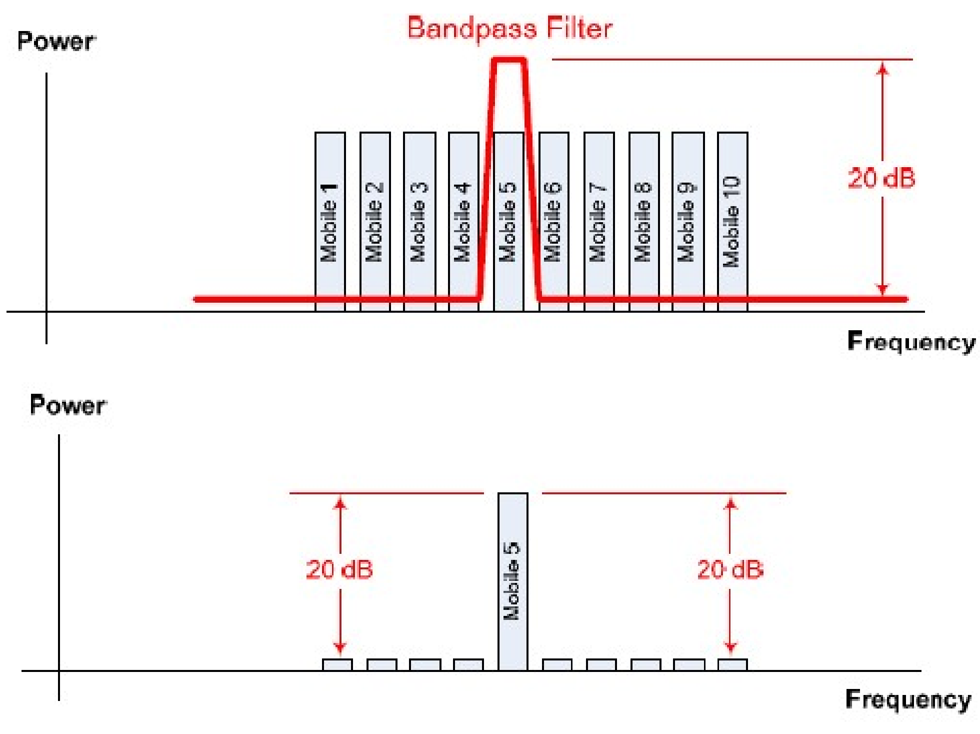
n	
2	0,58
2,5	0,43
3	0,32
3,5	0,24
4	0,17

Co-channel Interference, cont'd

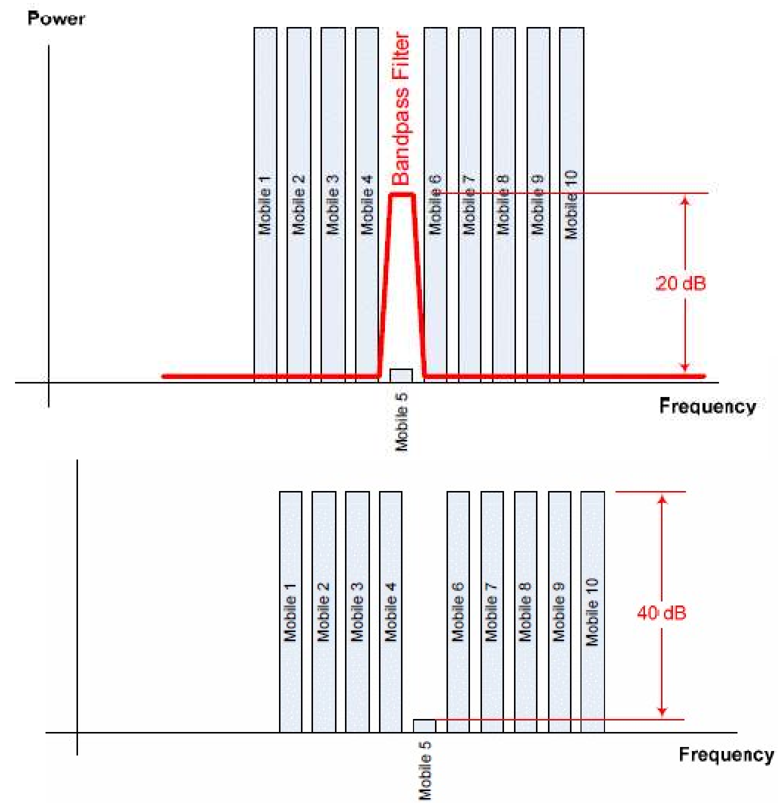
- **Example 3.2:**
  - **In U.S. AMPS system, S/I should be 18dB or higher for acceptable voice quality**
  - **Assuming co-channel interference from 1^{st} tier cell only, which are at equal distances from central cell,**
  - **Assuming a path loss exponent of n=4, then**
  - **Cluster size N > 6,49, i.e.,**
  - **Minimum cluster size is 7 to meet the desired SNR of 18dB**

Adjacent Channel Interference

- It results from imperfect receiver filters which allow nearby frequencies to leak into the passband
- It affects the reverse link, due to the variation of mobile locations wrt to the BS



All mobiles at same distance from BS
Successful reception

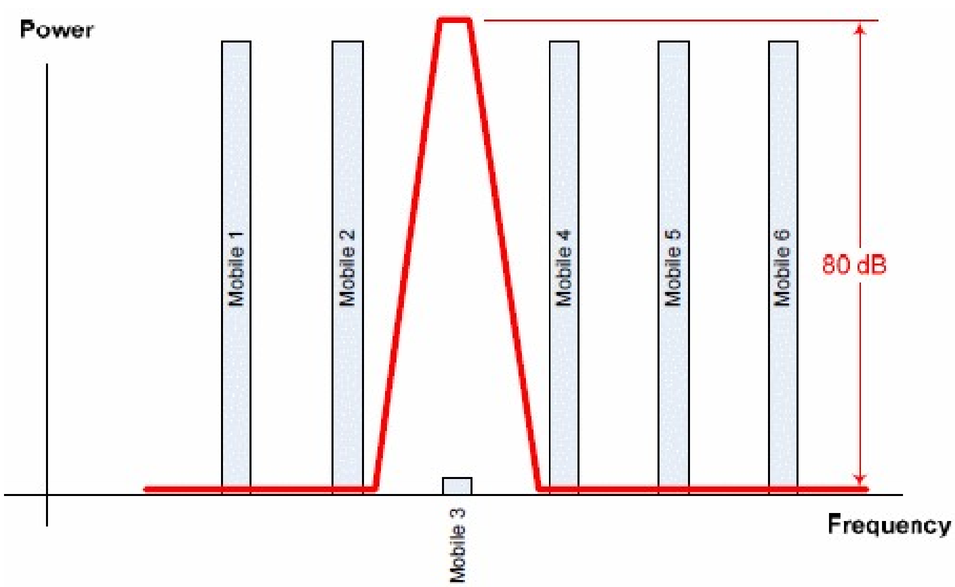


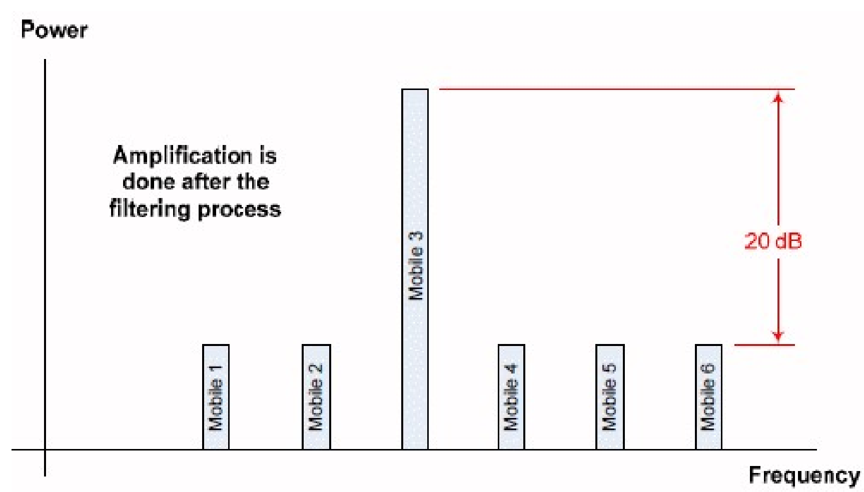
Mobile 5 further from BS
Unsuccessful reception

Solving Adjacent Channel Interference

- **Distribute channels, so that no adjacent channels are assigned to the same cell**
- **Example 3.3:**
  - **N = 7**

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
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
…	…	…	…	…	…	…





Channel Assignment Strategies

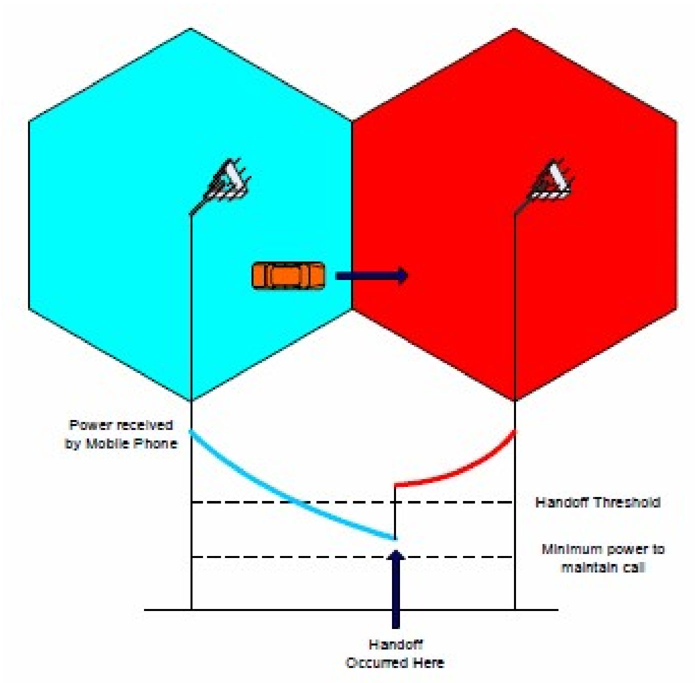
- **Channel Assignment is the process of allocating the appropriate channels to each cell, to maximize the network quality (ex. Maximize capacity, reduce interference, etc)**

  - **Fixed Channel Assignment:** **A specific number of channels and frequencies is assigned to each cell**

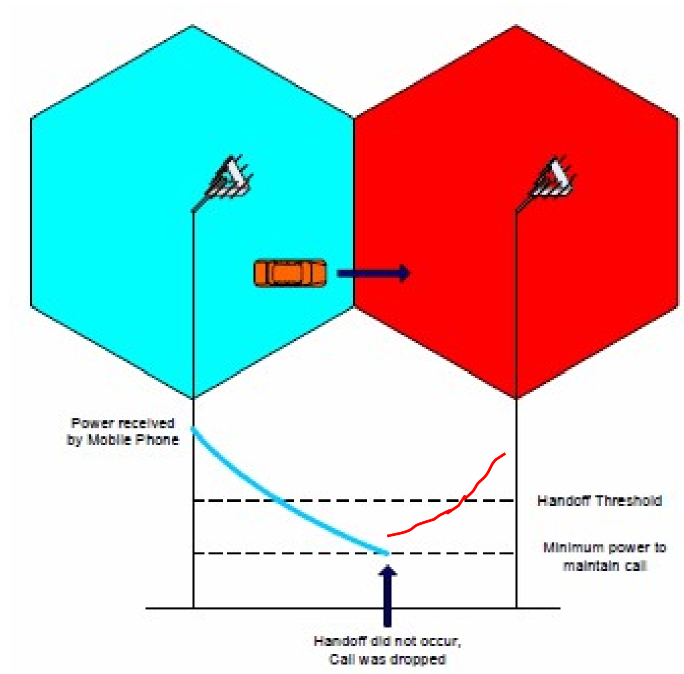
  - **Dynamic Channel Assignment:** **Any channel may be allocated to any cell during the system operation. Its position (cell) is determined on a demand-basis**

Handoff Strategies

- Handoff (HO) is the process of transferring a call from one cell to the other (as user moves), without disconnecting the call
- Serving handoffs is more important than new calls
- Handoff mechanisms should provide a transfer of the call transparently to the user



Successful Handoff



Unsuccessful Handoff

Trunking Theory

- Trunking is the concept that allows a large number of users to be served by a smaller number of channels (or other type of servers, ex. Customers at supermarket counters, etc)
- It is based on statistical analysis of user requests for service
- If a new call request is made and there is no channel available, then
  - The call request is blocked (Blocked Calls Cleared System)
  - The call is placed in a queue for several seconds, until a channel becomes available (Blocked Calls Queued System)
- 1 Erlang (E) is the amount of traffic intensity carried out by a completely occupied channel
  - = 1 call with a duration 1 hour over a channel every hour
  - = 2 calls with a duration of 30 mins each over a channel every hour
  - = 30 calls with a duration of 4 mins each over a channel every 2 hours
  - A channel that carries 2 calls with duration 5 mins each over an hour carries traffic equal to 1/6 E (=2*5/60)

Trunking Theory, cint'd

A(user):	**the traffic intensity per user (Erl)**
μ:	**Average number of call requests per unit time (ex. Erl /min)**
H:	**Average duration of a call (ex. Min)**
A:	**Total offered traffic intensity (Erl) from U number of users**
When A (offered) > C (capacity), then the traffic carried by the system is the max. number of channels (C) in Erl.	

$$A_{user} = \mu H$$

$$A = U\ A_{user}$$

Trunking Theory, cont'd

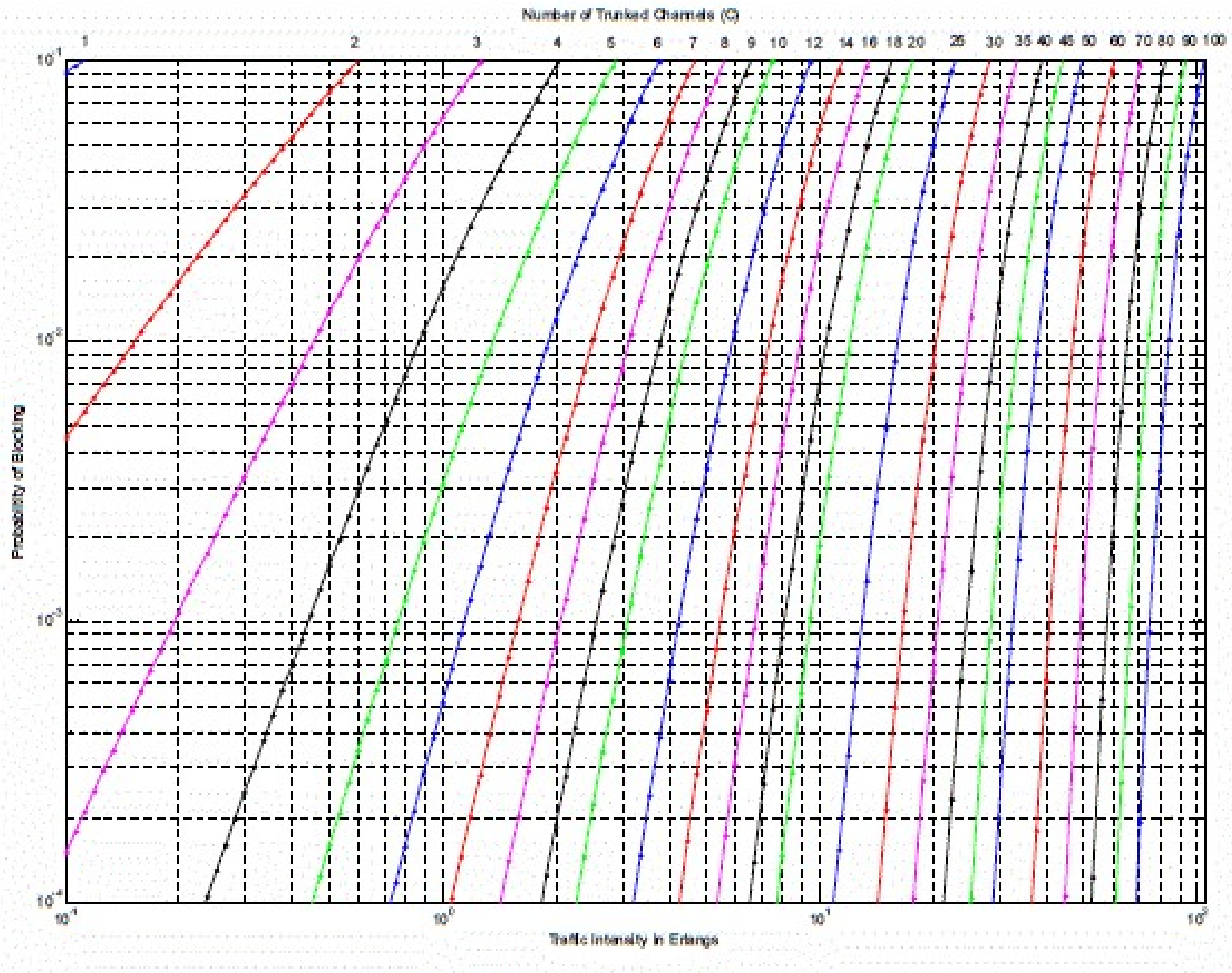
- Network traffic congestion is measured by Grade of Service **(GoS)**
- It denotes the Probability that a call will be blocked or be delayed beyond a specified period
- The GoS, offered traffic intensity **(A)** and number of channels **(C)** of a system are interrelated through the **Erlang B** formula

$$P_r[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GoS$$

Table 2.4 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 Chart



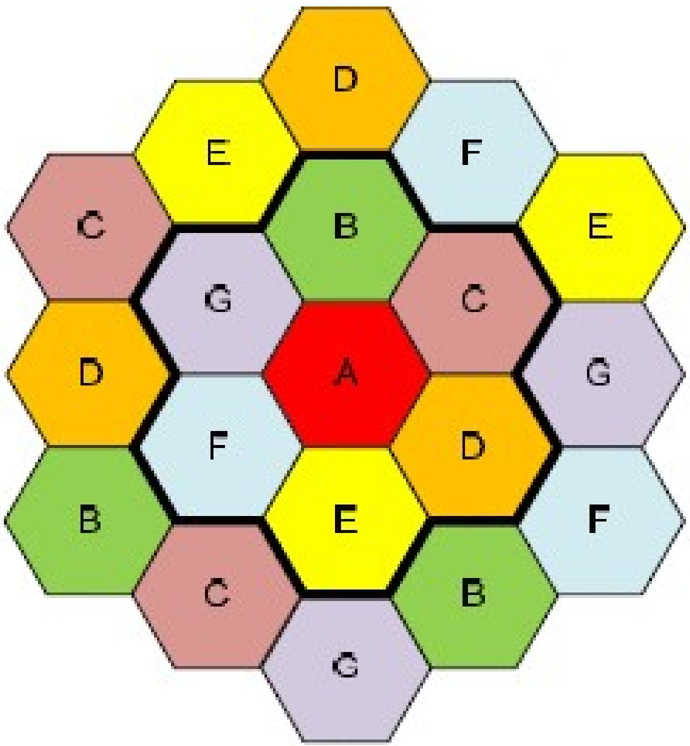
Trunking Efficiency

- Traffic supported does not increase linearly with the available channels
- The more channels grouped together at a cell, the higher the system capacity

- Example 3.4:
  - 1 group of 10 trunked channels at GoS 1% → 4,46 E
  - 2 groups of 5 trunked channels each at GoS 1% → 2*1,36 = 2,72 E

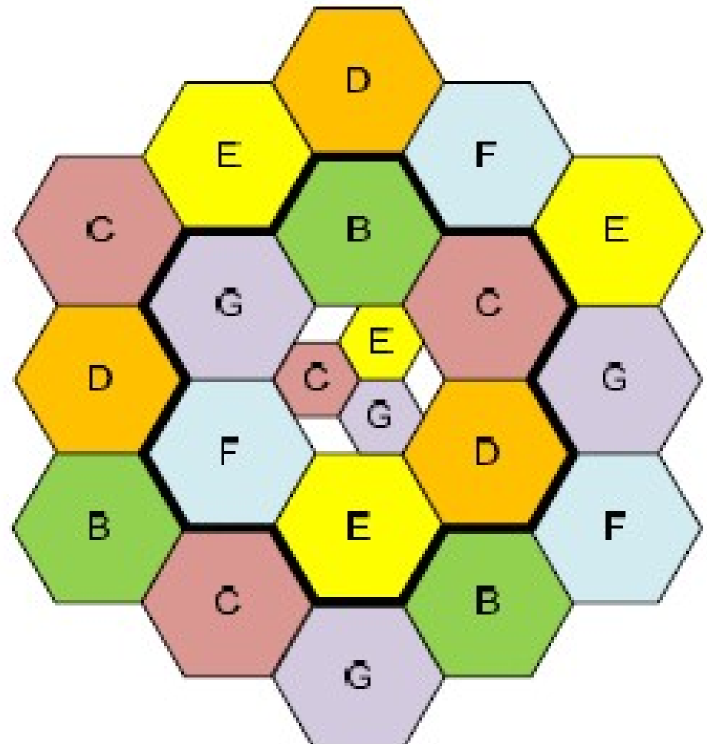
Improving Capacity in Cellular Systems

- **Cell splitting**
  - **Cell radius gets halved, and Tx Power (P) should be appropriately reduced (based on path loss exponent, n)**



(A):
Cell, with radius R

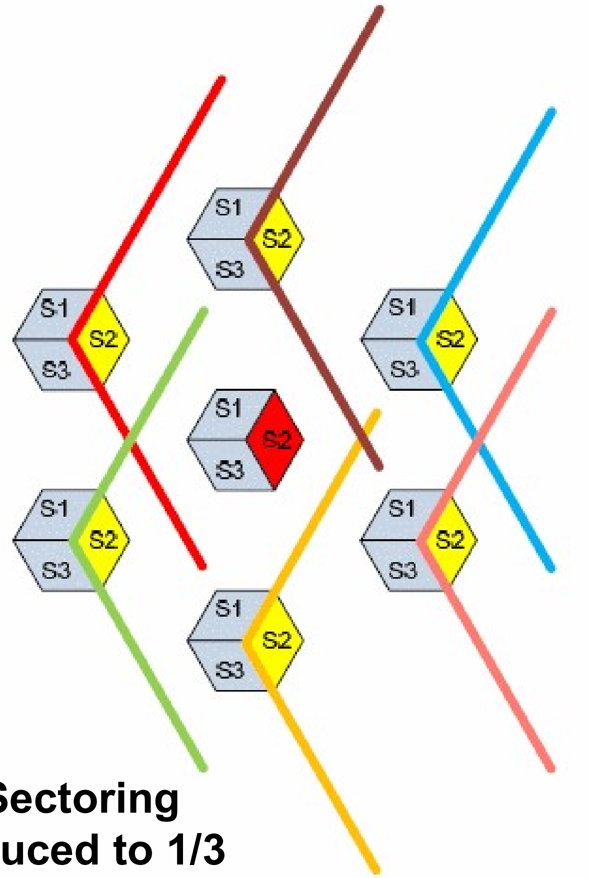
$$P_B = \frac{P_A}{2^n}$$



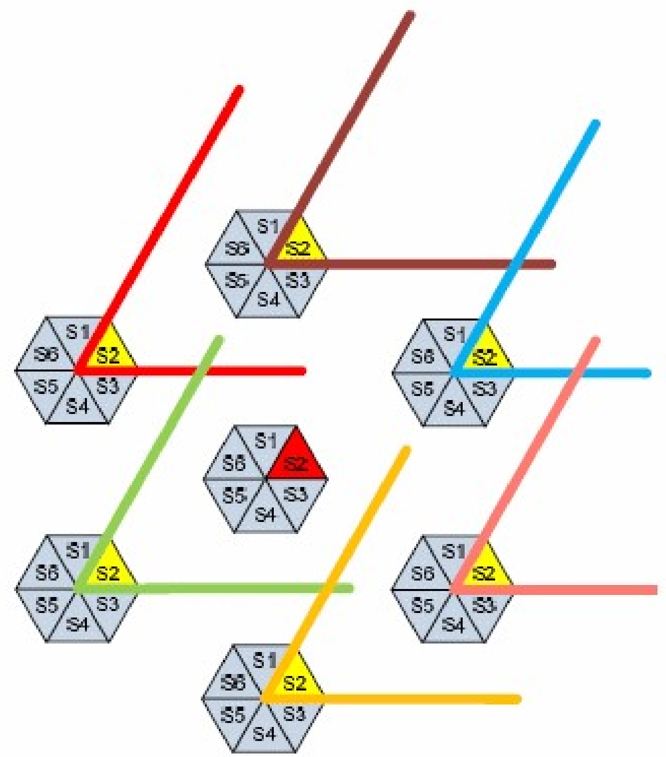
(B):
Central cell gets split to 3 smaller, each with radius R/2

Improving Capacity in Cellular Systems, cont'd

- **Sectoring**
  - **Directional antennas are deployed, thus:**
    - **a cell coverage area is divided in various sectors and**
    - **Co-channel interference is reduced**



120 degrees Sectoring
Interference reduced to 1/3



60 degrees Sectoring
Interference reduced to 1/6

Example 3.5: Network Dimensioning & Cost Estimation

Network Info		
Communication environment	a1	Shadowed Urban Cellular
Total Environment Losses (dB)	a2	30
Area (Km2)	a3	8000
Population (million people)	a4	5
Target service penetration	a5	90%
Target market share	a6	15%
Peak Traffic profile (min call per hour per 5 persons)	a7	1,1
Average Peak Traffic profile (min call per 5 hours per 20 persons)	a8	1
Network targeted GoS	a9	1,00%

Link Budget		
Tx power (W)	b1	10
Tx Antena gain (dB)	b2	18
Tx line losses (dB)	b3	2
Rx Sensitivity (dBm)	b4	-80
Rx antenna gain (dB)	b5	3
Rx line losses (dB)	b6	0
Min SNR (dB)	b7	18

Wireless System		
Operation Freq. Band (MHz)	c1	800
Channel Bandwidth (KHz)	c2	100
Access Technology	c3	FDMA
Freq. Block Size (MHz)	c4	5

Cost Data		
Cost per BS (K€)	d1	200,00
Cost per Freq. Block Size (M€)	d2	1,00

Solution:

1. Determine deployment strategy
   (Peak vs Avg Traffic service)

2. From Link Budget, determine Number of Cells needed
   2.1 EIRP = 10log(b1)+b2-b3 = 56dBm
   2.2 IRL = b4+b6-b5 = -83dBm
   2.3 FSL = EIRP-IRL-Lair = 109 dB
   2.4 Dmax = 8,40 Km (from FSL formula)
   2.5 Cell Area = 183,57 Km2 (Hex Area = 2,6 R^2)
   2.6 Total Number of Cells = Total Area / Cell Area = 44

3. From User data, determine Offered Traffic per Cell
   3.1 Total Users = a4*a5*a6=675.000
   3.2 Max Traffic = a7/(5*60)*Max Users=2.475 Erl
   3.3 Max Traffic / cell = Max Network Traffic / Total Number of Cells = 56,25 Erl

4. From Erlang B formula, determine the channels per cell needed for targeted GoS
   4.1 Channels / cell = 70

5. From targeted SNR, determine min Cluster size
   5.1 N = 7 (Example 3.2)

6. Determine total number of Freq. blocks needed to be acquired (per cluster)
   6.1 Total channels needed = Channels per cell * Cluster size * 2 = 980
   6.2 Total spectrum needed = Total Channels * Channel Bandwidth = 98MHz
   6.3 Freq. Blocks needed = ROUND(Total Spectrum / Block size) = 20

7. Estimate total cost (due to BS and spectrum)
   7.1 Total BS cost = 8,80 M€
   7.2 Total spectrum cost = 20 M€
   7.3 Total investment cost = 28,8 M€

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