WIRELESS PERSONAL COMMUNICATIONS SYSTEMS

INTERFERENCE LIMITED COMMUNICATIONS

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THE BIG PICTURE (1)

CELLULAR = CHANNEL REUSE
CELL SPLITTING
HANDOFF

AMOUNT OF CHANNEL REUSE DEPENDS ON HOW MUCH INTERFERENCE YOU CAN TOLERATE

RESISTANCE TO INTERFERENCE IS MEASURED BY γ_{req} THE SIGNAL-TO-INTERFERENCE RATIO REQUIRED FOR GOOD QUALITY.

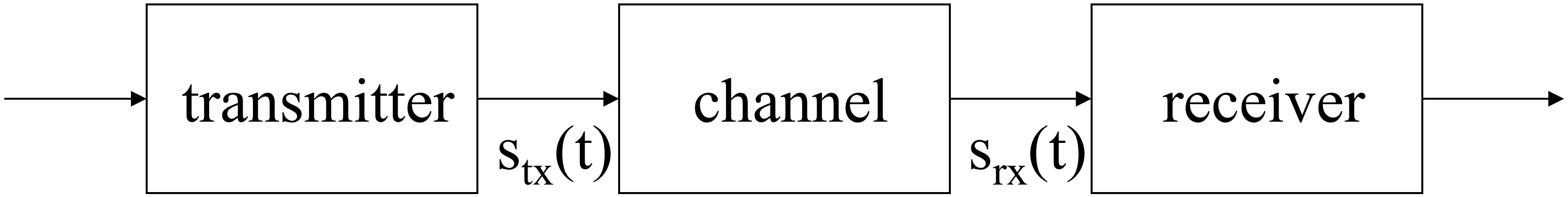
THE BIG PICTURE (2)

AN IMPORTANT FIGURE OF MERIT OF A CELLULAR SYSTEM IS THE **CAPACITY** MEASURED AS THE NUMBER OF PHYSICAL **CHANNELS PER CELL**.

A CLOSELY RELATED MEASURE IS
CELLULAR EFFICIENCY=CAPACITY/SYSTEM BANDWIDTH

EFFICIENCY DEPENDS ON BOTH γ_{req} AND BANDWIDTH PER PHYSICAL CHANNEL

Communications System



s(t) volts is a signal

P=Average[$s^2(t)$] watts is power

Power <u>ratio</u> is often measured in decibels

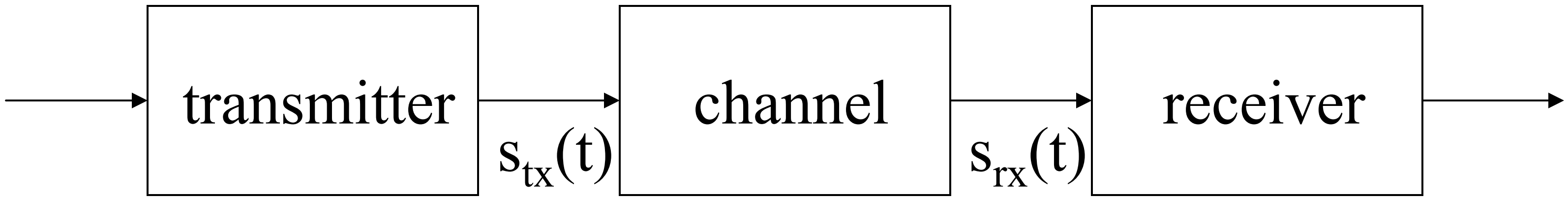
$10\log_{10}(P_1/P_2) = T$ dB

If P_2= 1 Watt, T dBW measures the power of P_1 (relative to 1 W)

If P_2= 1 milliwatt, T **dBm** measures the power of P_1 (relative to 1 mW)

dBm is a common unit of power of wireless signals

Distortion
(noise and interference)



$s_{rx}(t) - Gs_{tx}(t)$ is the distortion caused by the channel

$G<1$ is channel gain

$P_{distortion}=\text{Average}[s_{rx}(t) - Gs_{tx}(t)]^2$ is the distortion power

$P_{receive}= \text{Average}[Gs_{tx}(t)]^2$ is received signal power

$\gamma= P_{receive}/ P_{distortion}$ is the signal-to-distortion ratio

In many communications systems the difference between $Gs_{tx}(t)$ and $s_{rx}(t)$ is noise and γ is the signal-to-noise ratio SNR (S/N).

In cellular systems the difference is mainly interference from other signals and γ is signal-to-interference ratio SIR (S/I)

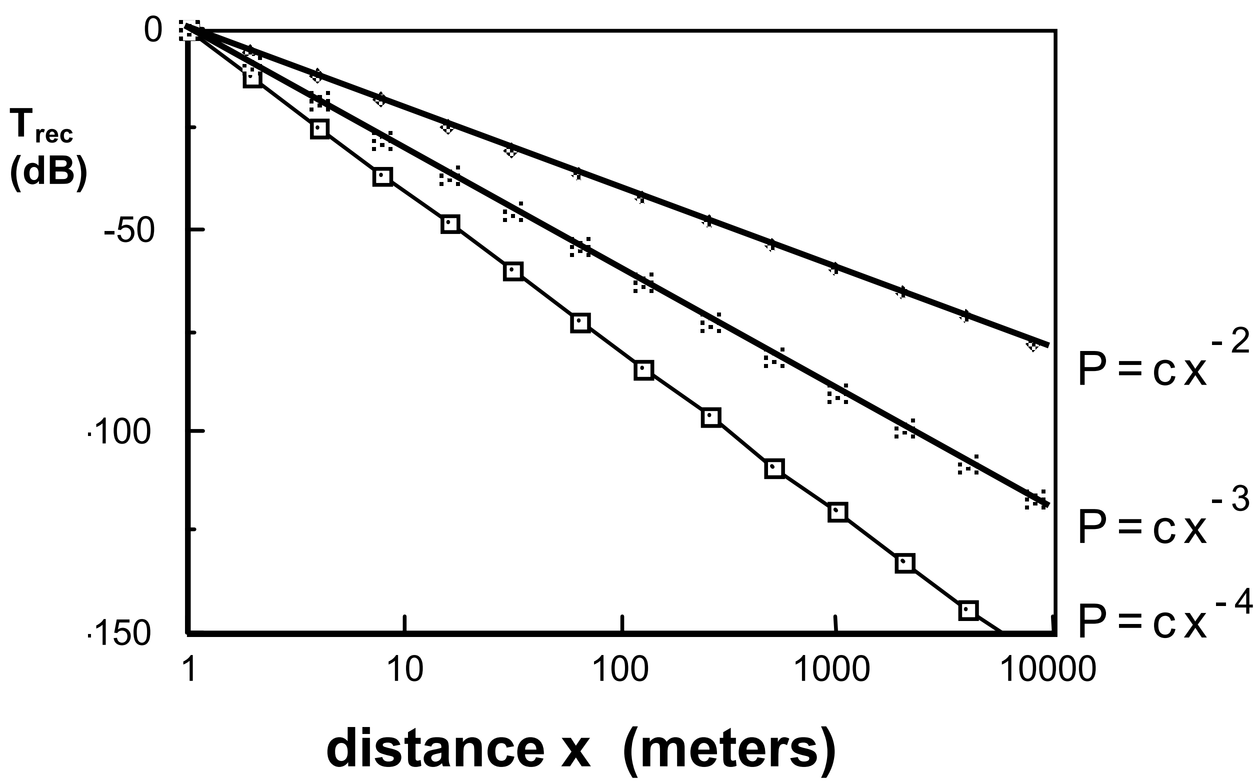
Required signal-to-interference ratio

In many applications, engineers specify a signal-to-interference ratio γ_{req}. They assume the signal quality is acceptable if $\gamma > \gamma_{req}$. Otherwise it is unacceptable. The value of γ_{req} depends on a lot of details of the transmitter receiver and channel. For example FM radios usually have much lower γ_{req} than AM, so we say FM is more tolerant of interference, or “more robust”.

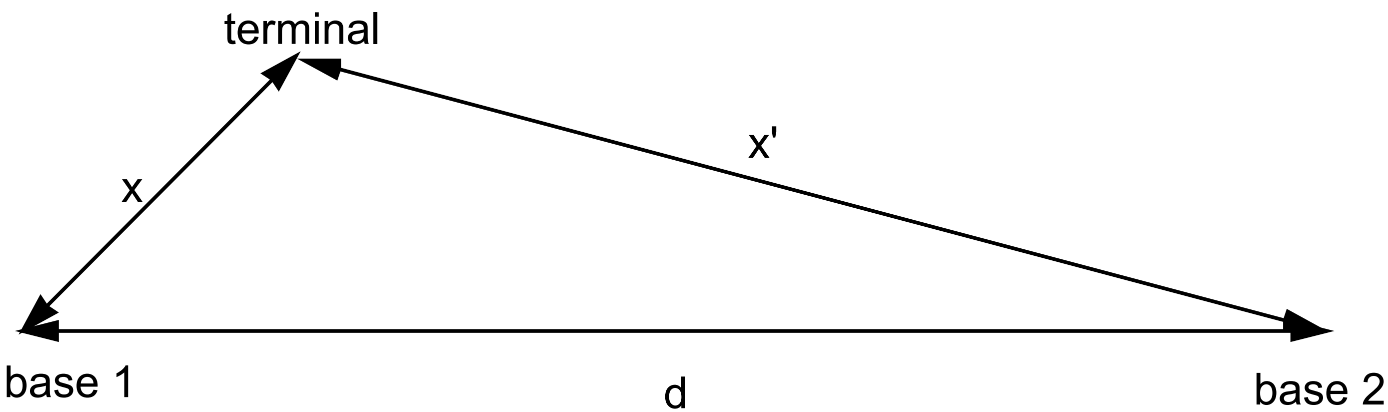
SIGNAL STRENGTH DECREASES WITH DISTANCE

$$P_{receive} = const \times P_{transmit} / x^{\alpha}$$ watts

$$T_{receive} = 10\log_{10} P_{receive} = const - \alpha \log_{10} x$$ dBm



SIGNAL-TO-INTERFERENCE RATIO

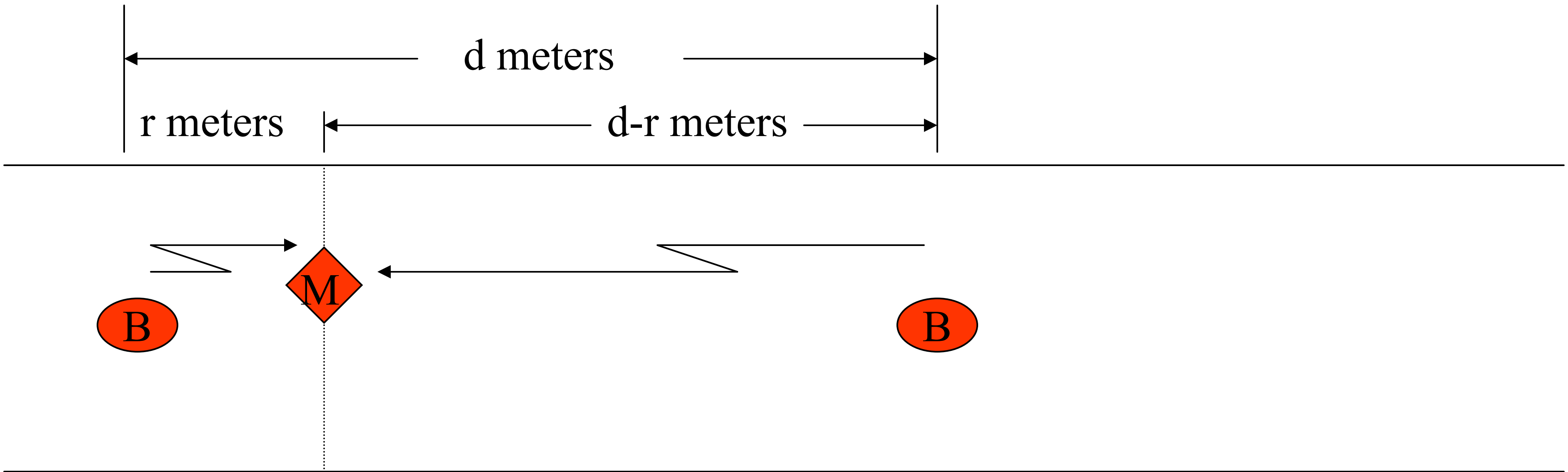


$$P_S = const \times P_{transmit} / x^{\alpha}$$

$$P_I = const \times P_{transmit} / (x')^{\alpha}$$

$$P_S / P_I = \gamma = (x' / x)^{\alpha}$$

2 INTERFERING BASE STATIONS

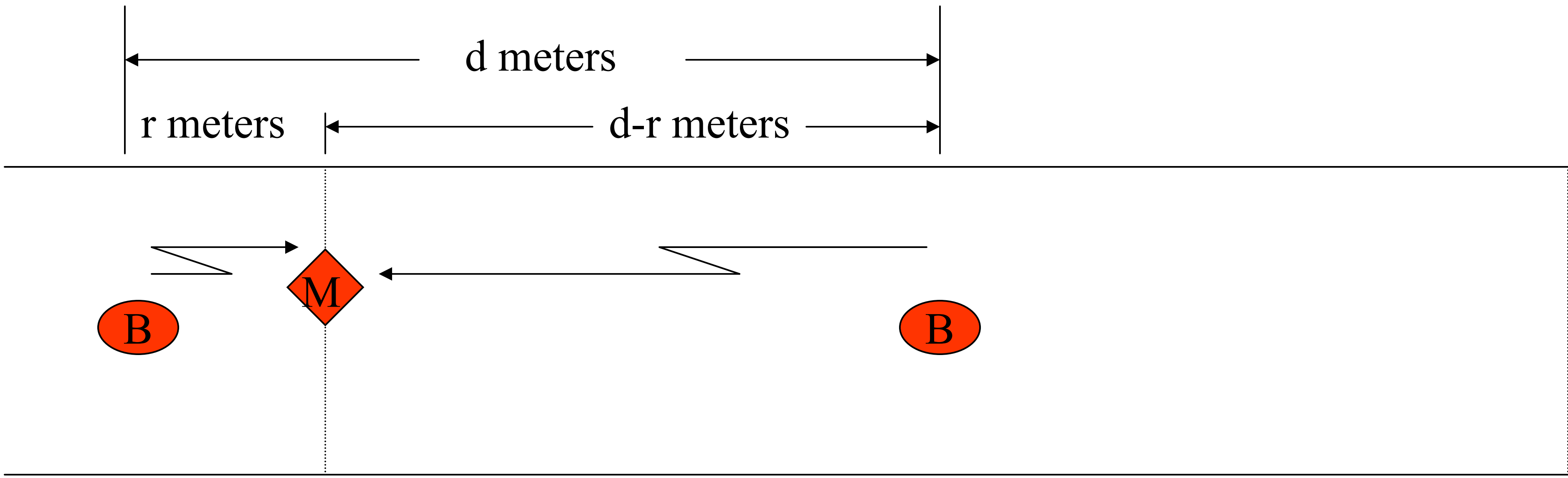


d meters: distance between interfering base stations

r meters: maximum distance to serving base station *cell radius*

SIGNAL-TO-INTERFERENCE RATIO

depends on d/r



$$P_S = const \times r^{-\alpha}$$

$$P_I = const \times (d - r)^{-\alpha}$$

$$\gamma = \frac{P_S}{P_I} = (\frac{d}{r} - 1)^{\alpha}$$

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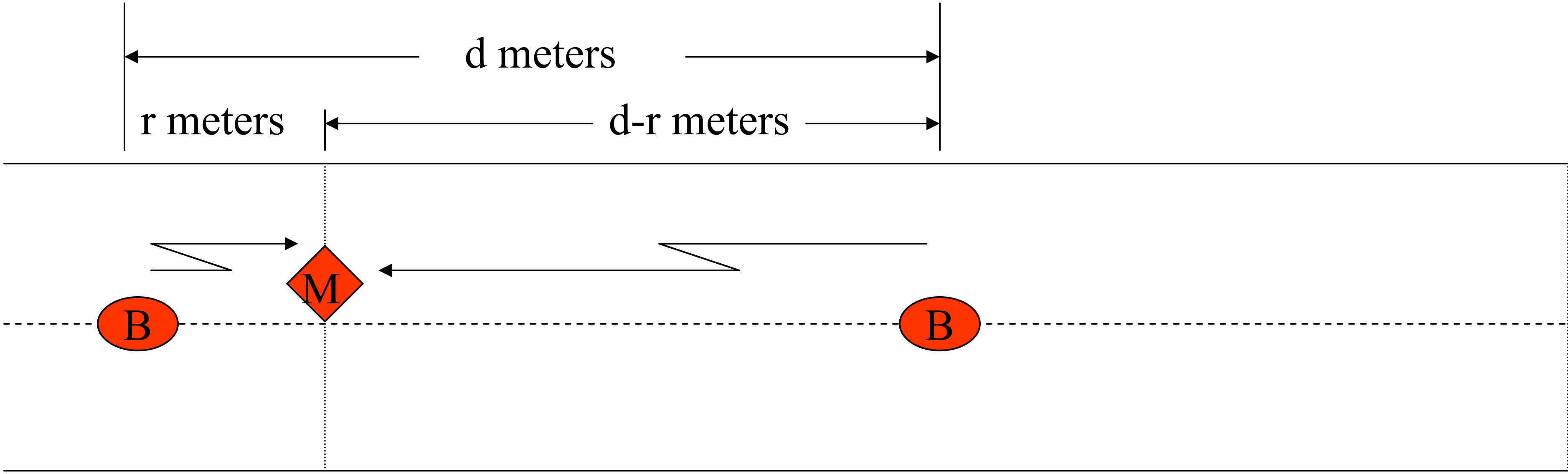
MINIMUM d/r TO MEET SIR REQUIREMENT

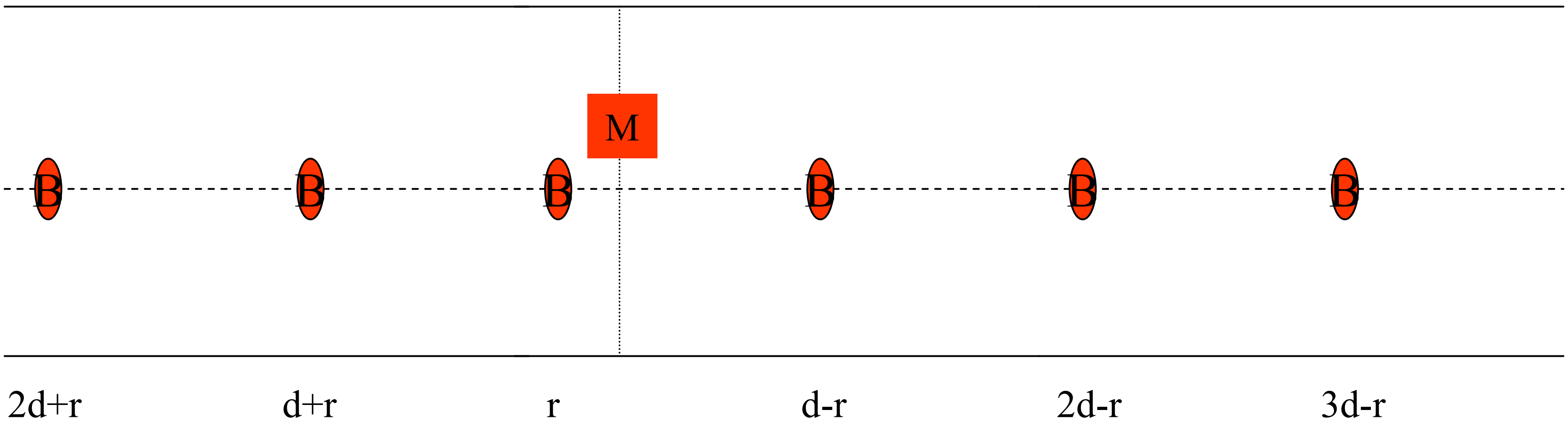


$$10\log_{10}\gamma \geq T_{req} \text{ dB} \Rightarrow$$

$$10\alpha\log_{10}(\frac{d}{r}-1) \geq T_{req} \Rightarrow$$

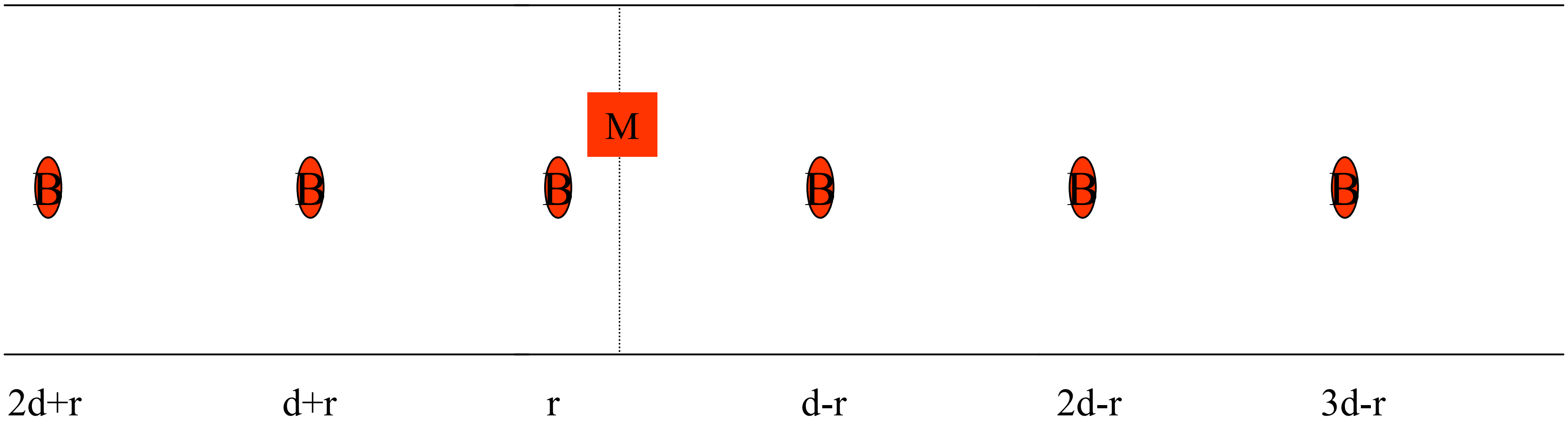
$$\frac{d}{r} \geq 10^{T_{req}/(10\alpha)} + 1$$

LINEAR ARRAY OF BASE STATIONS



SIGNAL-TO-INTERFERENCE RATIO

depends on d/r



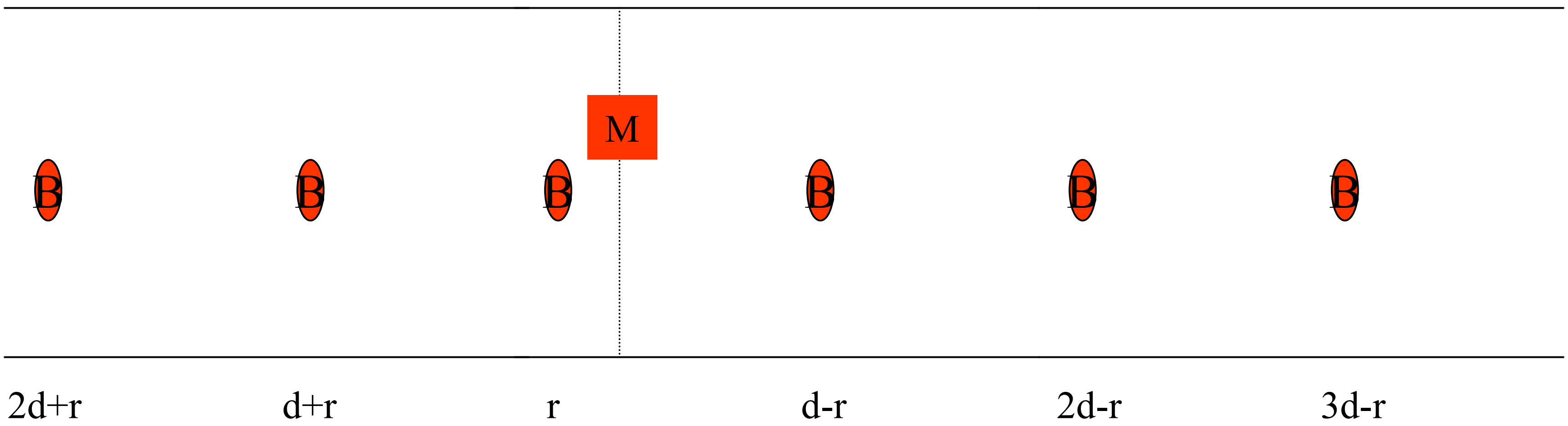
$$P_S = const \times r^{-\alpha}$$

$$P_I = const \times [(d-r)^{-\alpha} + (d+r)^{-\alpha} + (2d-r)^{-\alpha} + (2d+r)^{-\alpha} + \ldots]$$

$$\gamma = \frac{P_S}{P_I} = \frac{1}{[(d/r-1)^{-\alpha} + (d/r+1)^{-\alpha} + (2d/r-1)^{-\alpha} + (2d/r+1)^{-\alpha} + \ldots]}$$

MINIMUM d/r TO MEET SIR REQUIREMENT

(no simple formula)

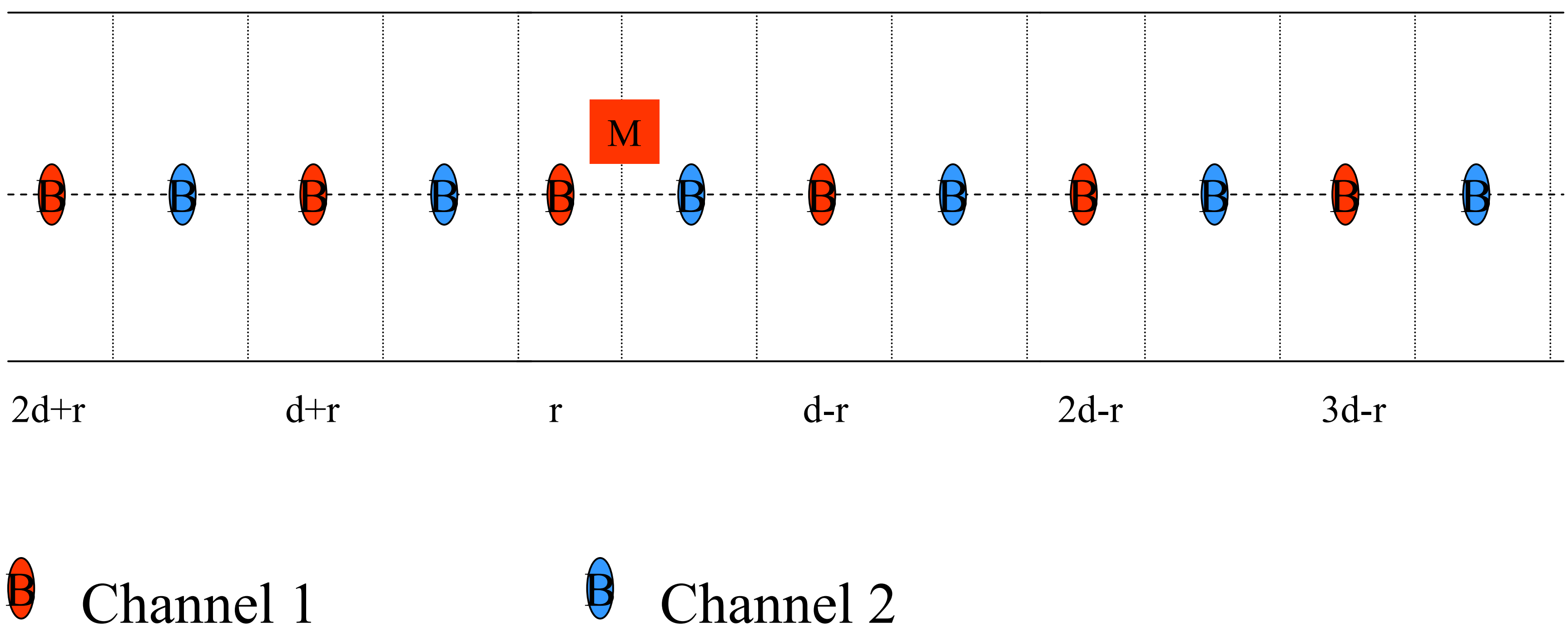


$$\gamma = \frac{1}{[(d/r-1)^{-\alpha} + (d/r+1)^{-\alpha} + (2d/r-1)^{-\alpha} + (2d/r+1)^{-\alpha} + \ldots]}$$

$$10\log_{10}\gamma \geq T_{req} \text{ dB} \Rightarrow$$

$$\frac{d}{r} \geq ???$$

2 CELL REUSE, d=4r



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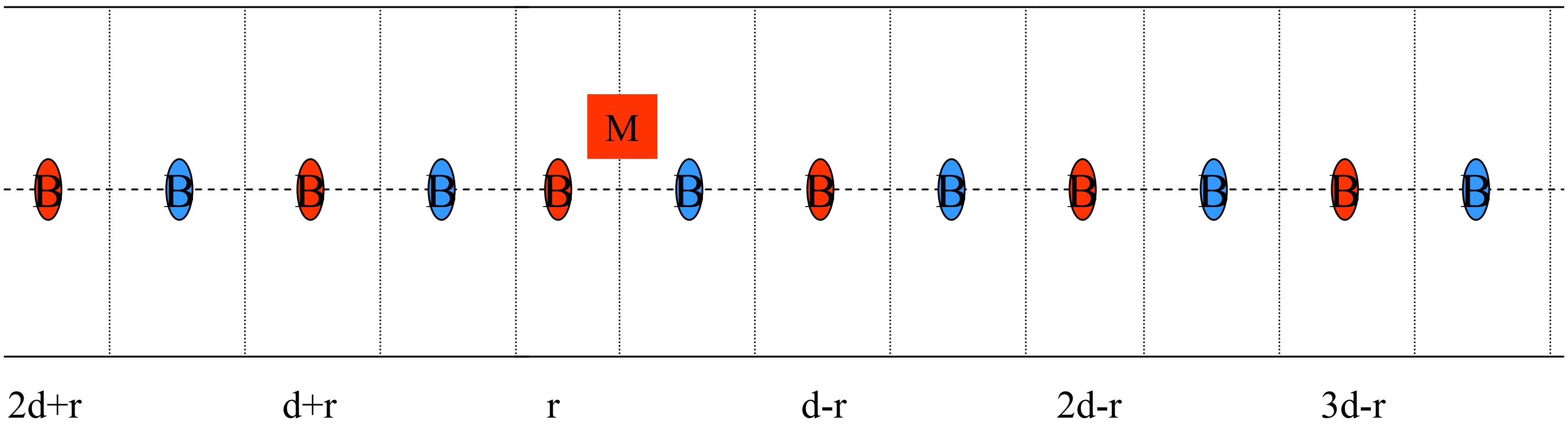
2 CELL REUSE, d=4r

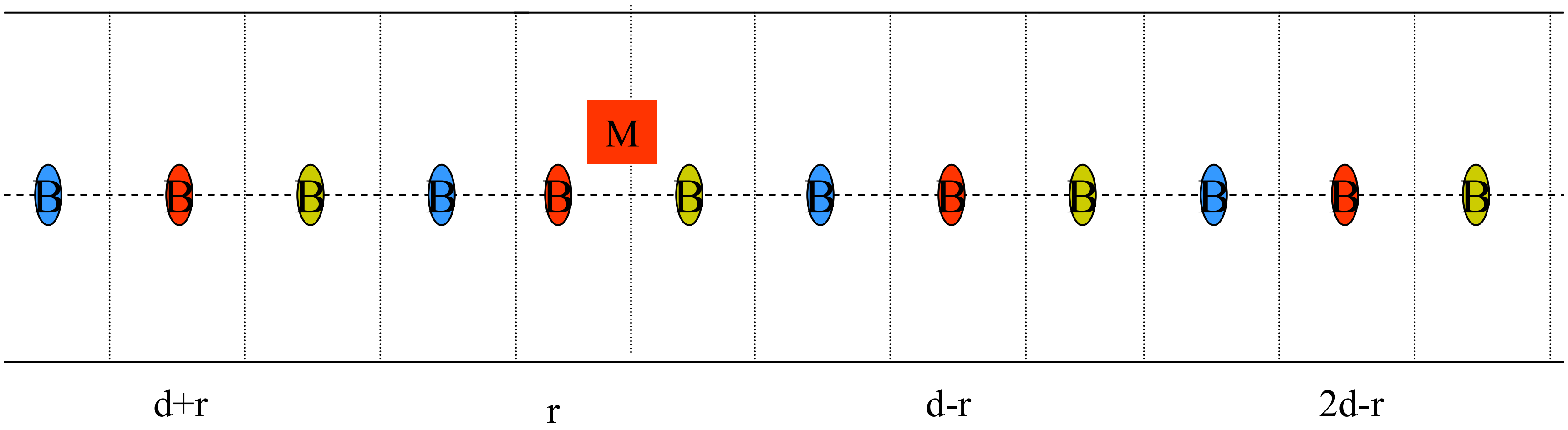


$$P_I = const \times [(3)^{-\alpha} + (5)^{-\alpha} + (7)^{-\alpha} + (9)^{-\alpha} + \ldots]$$

$$\gamma = \frac{P_S}{P_I} = \frac{1}{[(3)^{-\alpha} + (5)^{-\alpha} + (7)^{-\alpha} + (9)^{-\alpha} + \ldots]}$$

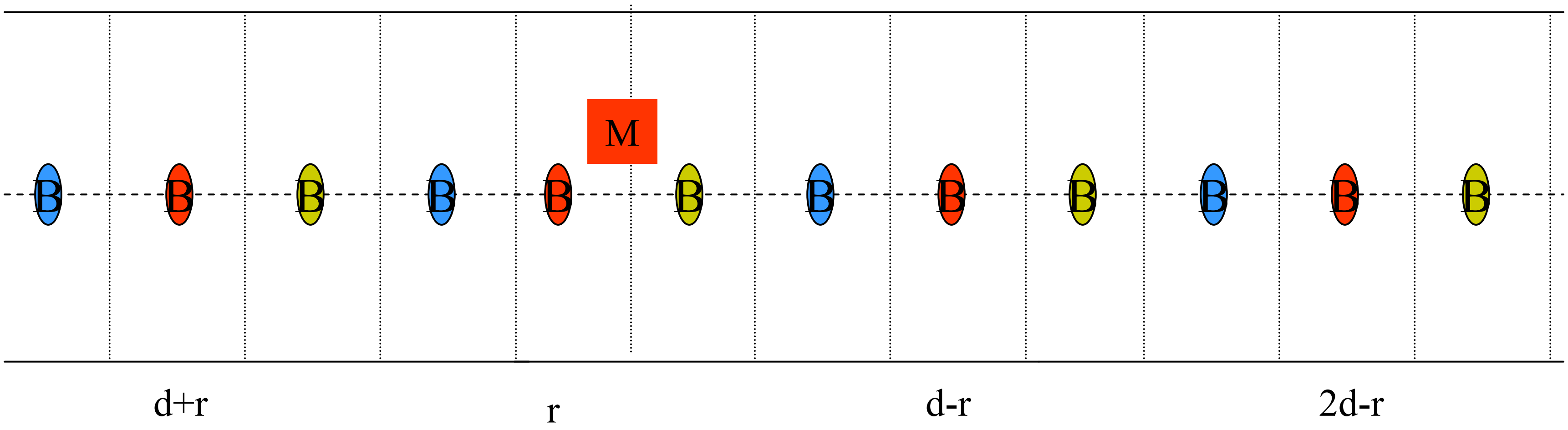
If α=4, γ=68.9 (T=18.4 dB)

3 CELL REUSE, d=6r



- Channel 1
- Channel 2
- Channel 3

3 CELL REUSE, d=6r



$$P_I = const \times [(5)^{-\alpha} + (7)^{-\alpha} + (11)^{-\alpha} + (13)^{-\alpha} + \ldots]$$

$$\gamma = \frac{P_S}{P_I} = \frac{1}{[(5)^{-\alpha} + (7)^{-\alpha} + (11)^{-\alpha} + (13)^{-\alpha} + \ldots]}$$

If α=4, γ=472 (T=26.7 dB)

N CELL REUSE d=2Nr

$$\gamma = \frac{1}{[(2N-1)^{-\alpha} + (2N+1)^{-\alpha} + (4N-1)^{-\alpha} + (4N+1)^{-\alpha} + (6N-1)^{-\alpha} + \ldots]}$$

$$10\log_{10}\gamma \ \geq \ T_{req} \text{ dB} \Rightarrow$$

$$N \geq ???$$

For cell planning find minimum N that meets SIR requirement

CELLULAR EFFICIENCY

NUMBER OF CHANNELS PER BASE STATION

System bandwidth:	B_S	Hz
Bandwidth per channel:	B_C	Hz
Number of channels:	B_S/B_C	channels
Reuse:	N	cells

Efficiency: $$\eta = \frac{B_S}{B_C N}$$ channels/cell

$$\eta / B_S = \frac{1}{B_C N}$$ channels/cell/MHz

CELLULAR EFFICIENCY

NUMBER OF CHANNELS PER BASE STATION

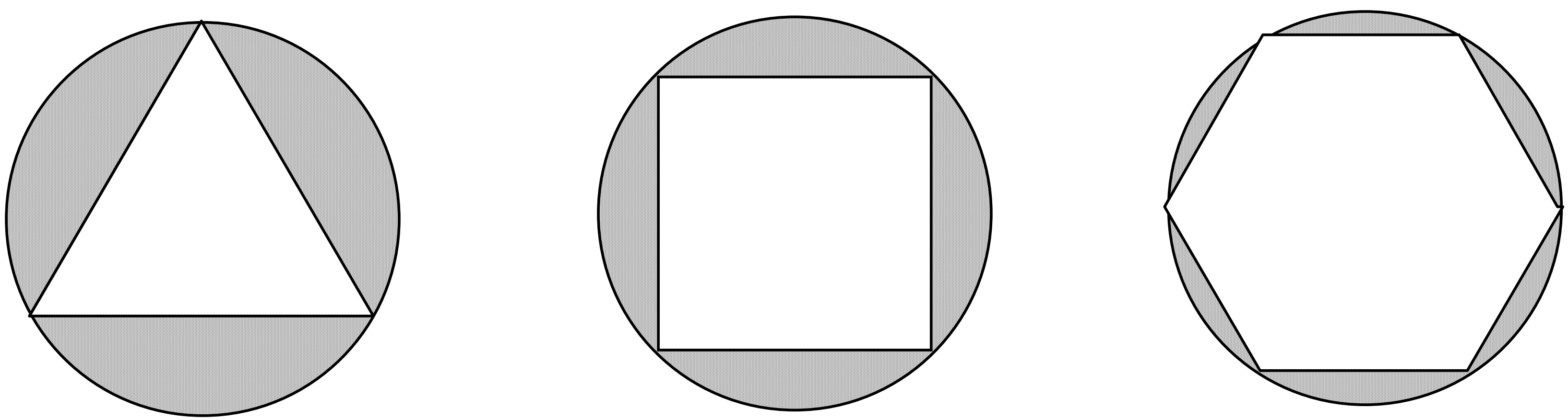
$$\eta / B_S = \frac{1}{B_C N}$$ channels/cell/MHz

Efficiency depends on bandwidth per channel and reuse

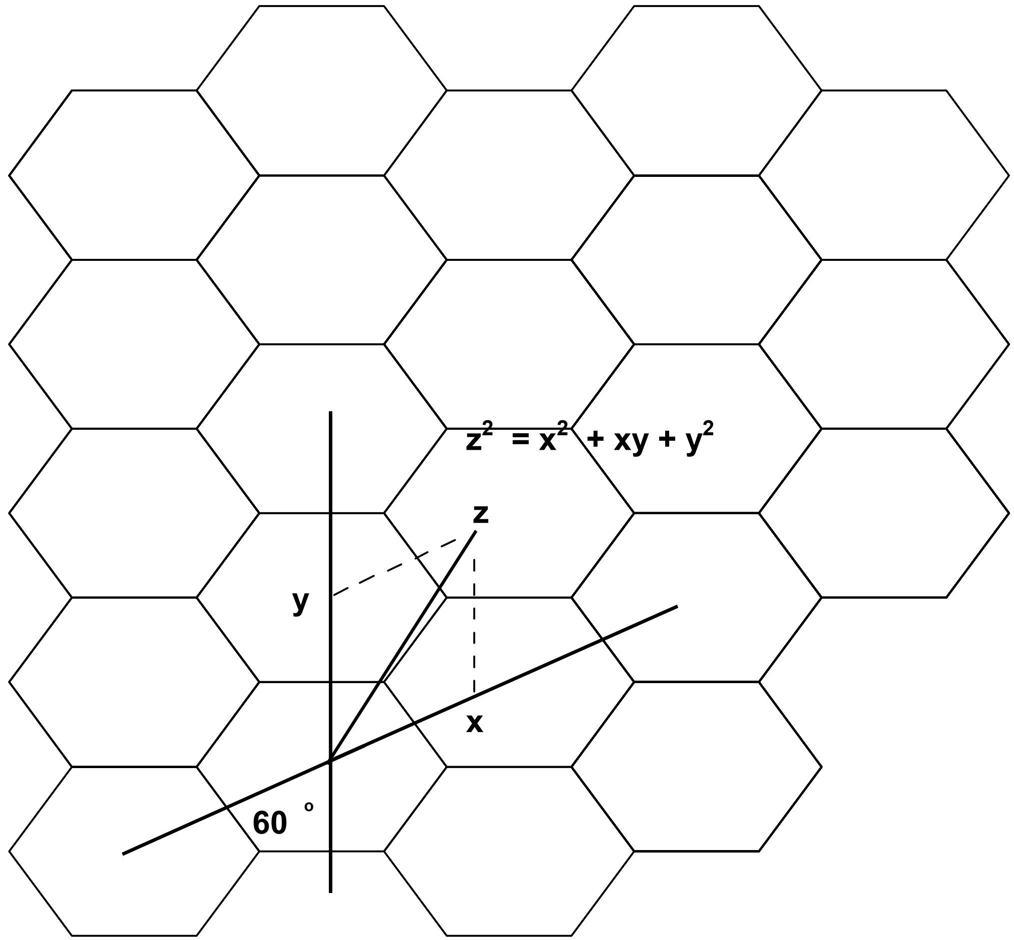
Reuse depends on T_{req} (interference sensitivity of transmission system)

Efficiency depends on bandwidth per channel and interference sensitivity of transmission system

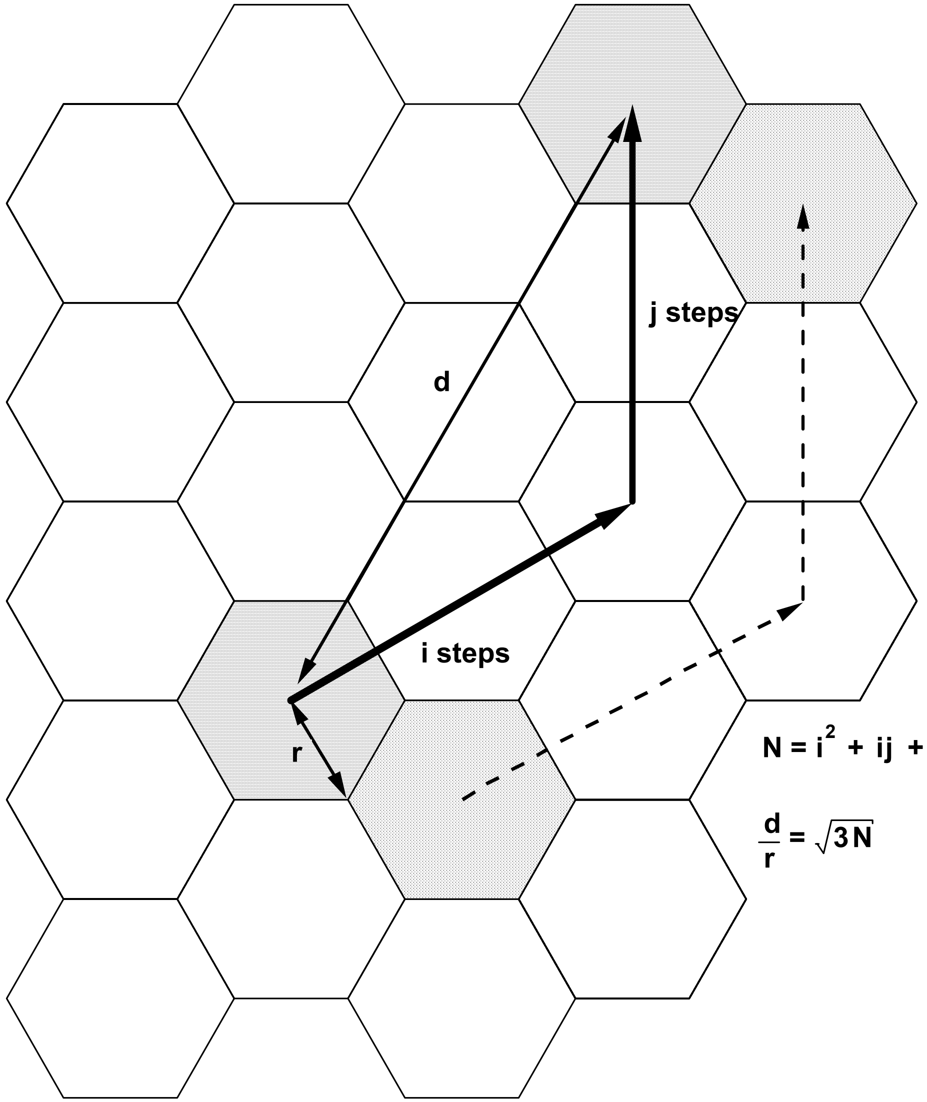
IDEAL CELL SHAPES



HEXAGON GEOMETRY



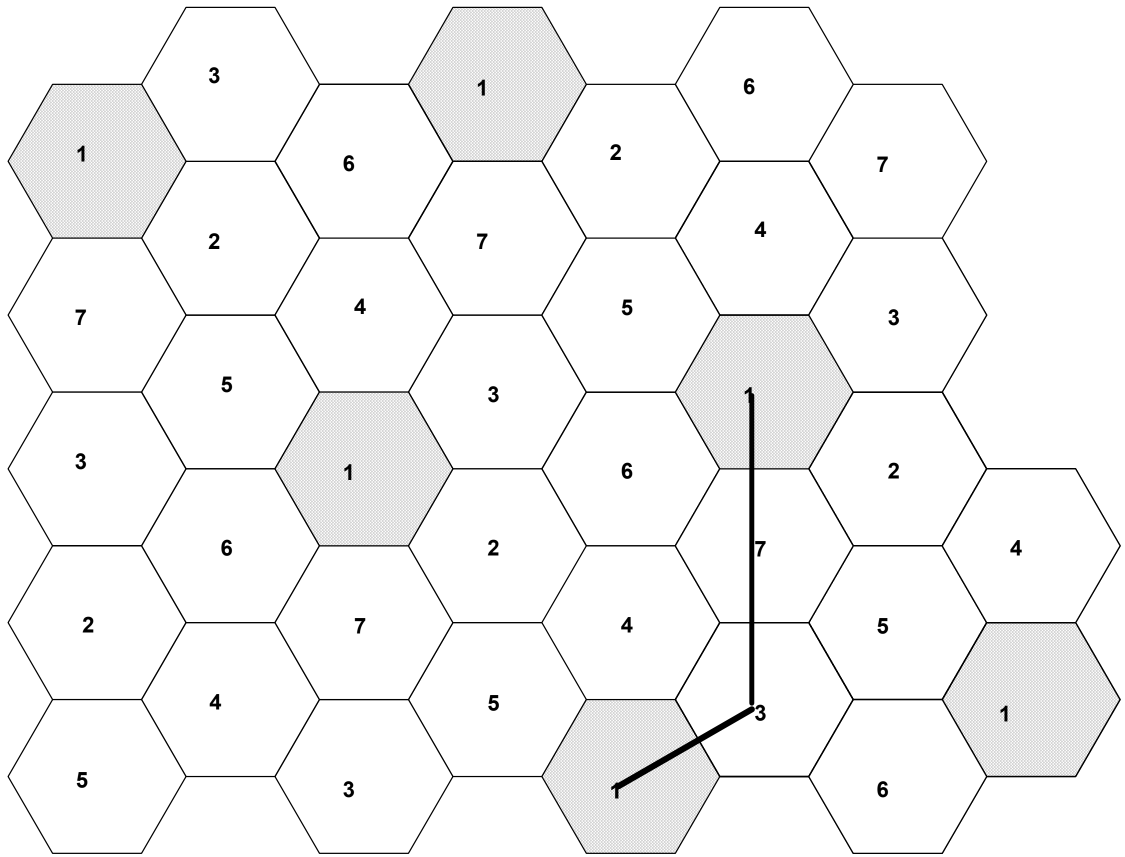
CELL PLANNING WITH HEXAGONS



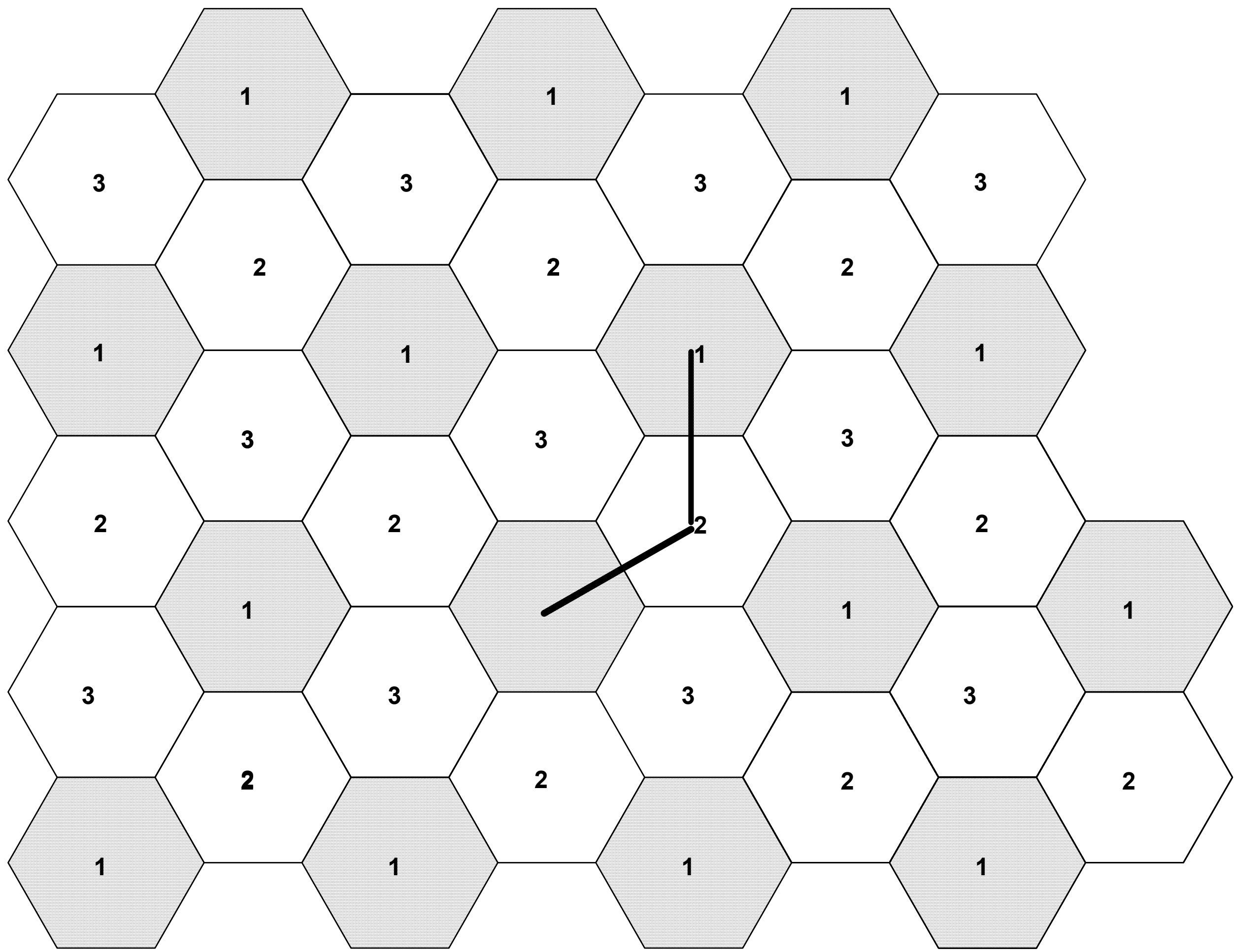
$$N = i^2 + ij + j^2$$

$$\frac{d}{r} = \sqrt{3N}$$

N=7 CELL REUSE
i=1, j=2



N=3 CELL REUSE
i=1, j=1



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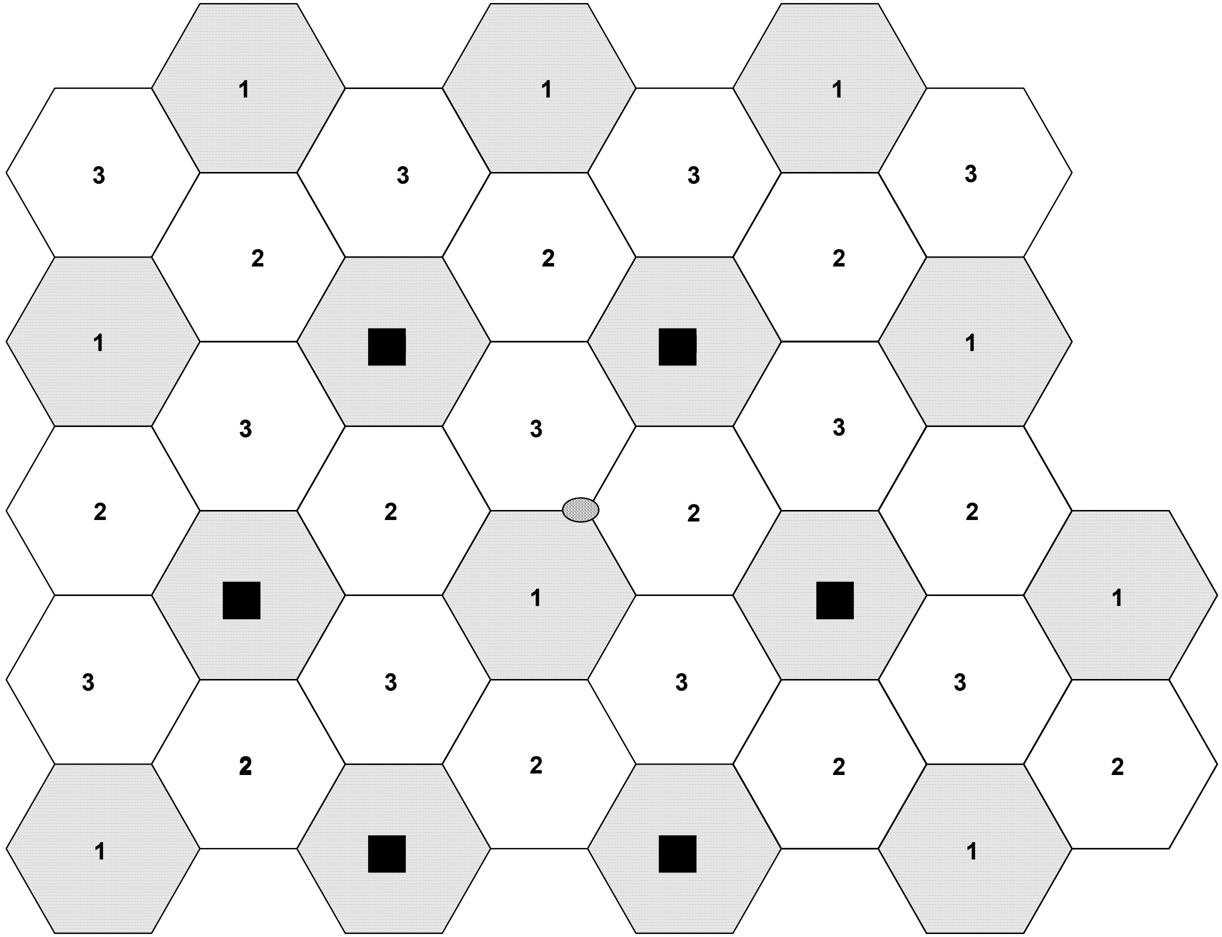
POSSIBLE REUSE FACTORS
N<100

CHANNEL SETS: $N=i^2 + ij + j^2$

j \ i	1	2	3	4	5	6	7	8	9
0	1	4	9	16	25	36	49	64	81
1	3	7	13	21	31	43	57	73	91
2		12	19	28	39	52	67	84	
3			27	37	49	63	79	97	
4				48	61	76	93		
5					75	91			

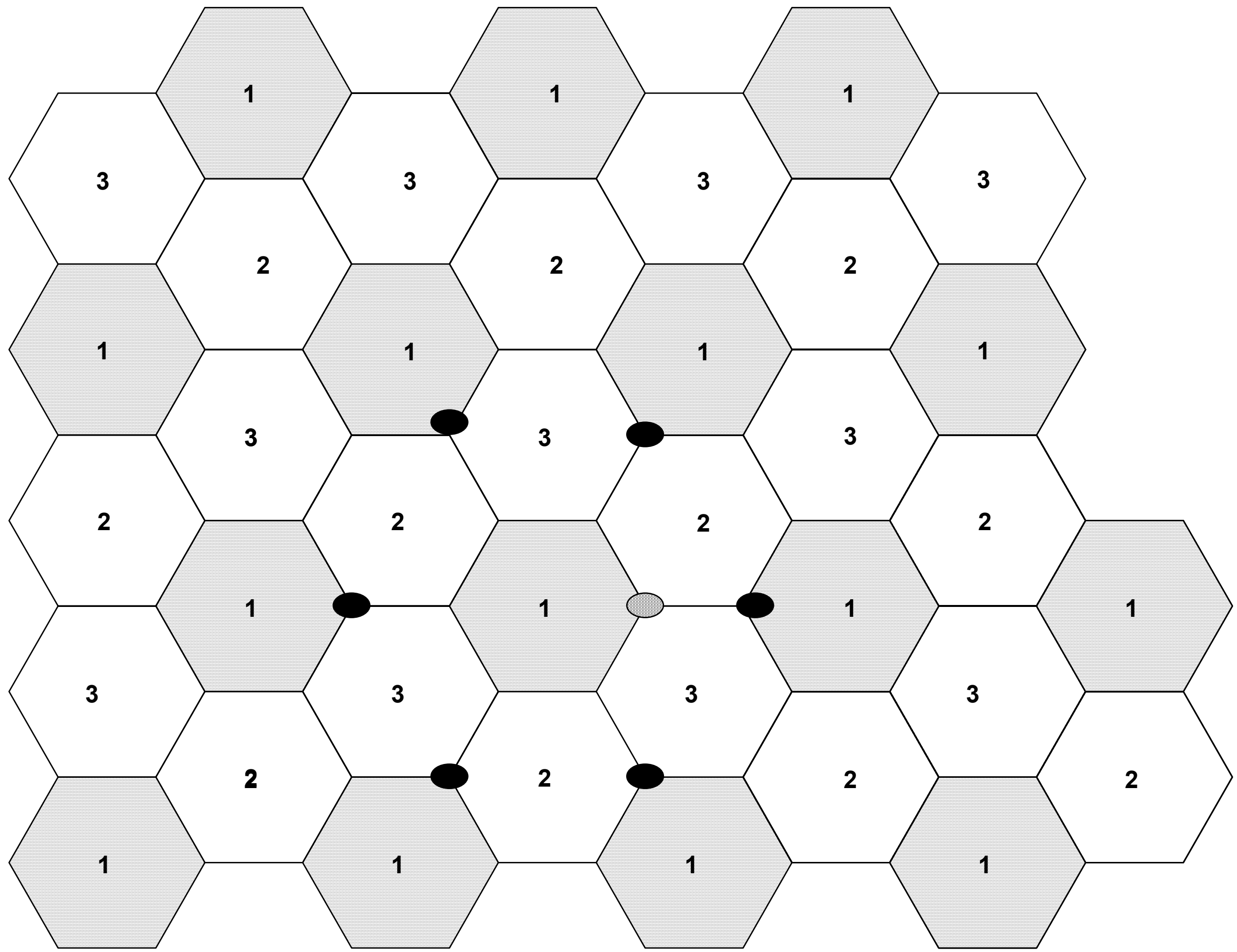
WORST-CASE AT TERMINAL, N=3



$$P_I = const \times P_{transmit}\left((2r)^{-\alpha} + 2\left(r\sqrt{7}\right)^{-\alpha} + 2\left(r\sqrt{13}\right)^{-\alpha} + (4r)^{-\alpha} \right) \quad \text{watts}$$

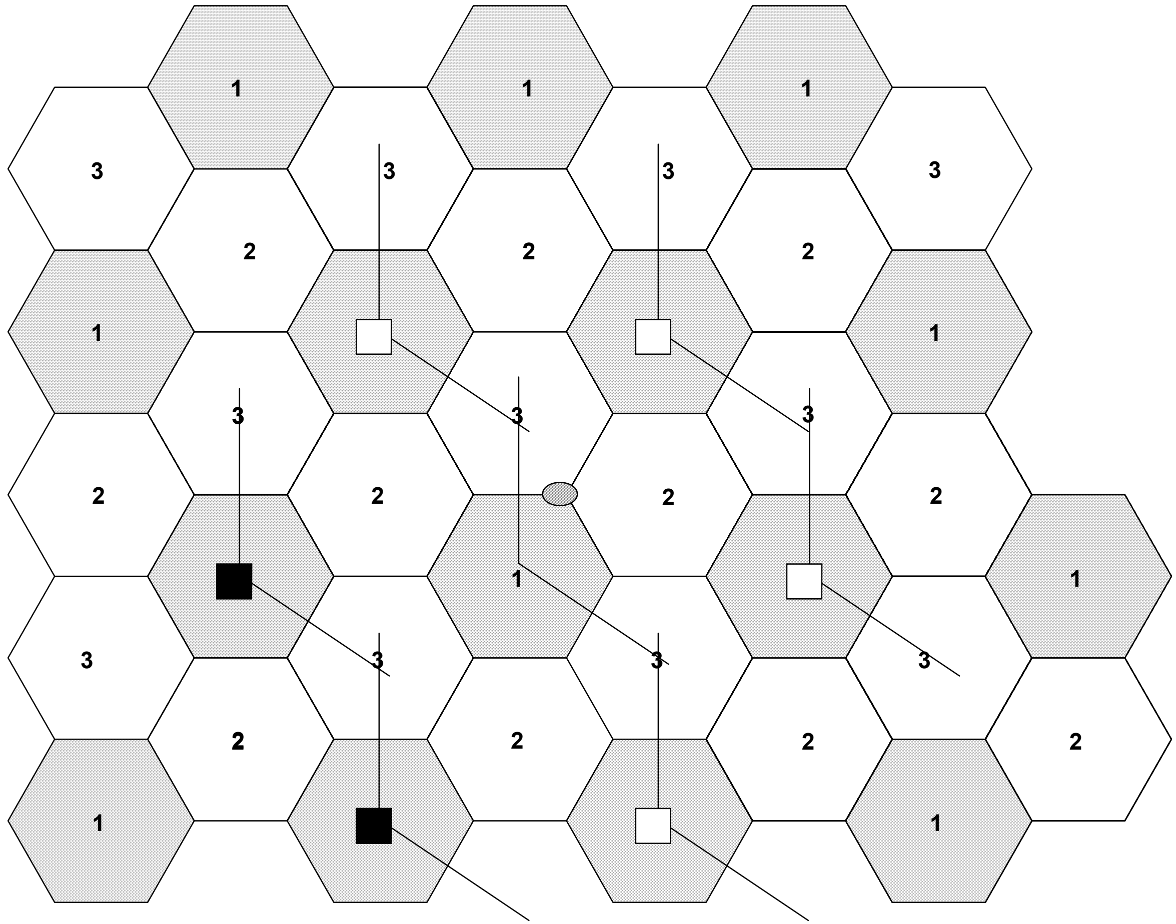
$$\gamma = \frac{1}{(2)^{-\alpha} + 2\left(\sqrt{7}\right)^{-\alpha} + 2\left(\sqrt{13}\right)^{-\alpha} + (4)^{-\alpha}}$$

WORST-CASE AT BASE, N=3



$$P_I = 6P_{transmit} \times const/(2r)^{-\alpha} \text{ watts} \qquad \gamma = const \times r^{-\alpha}/P_I = 2^{\alpha}/6$$

INTERFERENCE AT TERMINAL, N=3



$$\gamma = \frac{1}{\left(\sqrt{13}\right)^{-\alpha} + 4^{-\alpha}}$$

SIGNAL-TO-INTERFERENCE RATIO (dB)
N=3 REUSE, α=4   PROPAGATION

	omnidirectional antenna	120° sectors	60° sectors
base-to-terminal	9.2	20.1	24.1
terminal-to-base	4.3	16.1	19.1