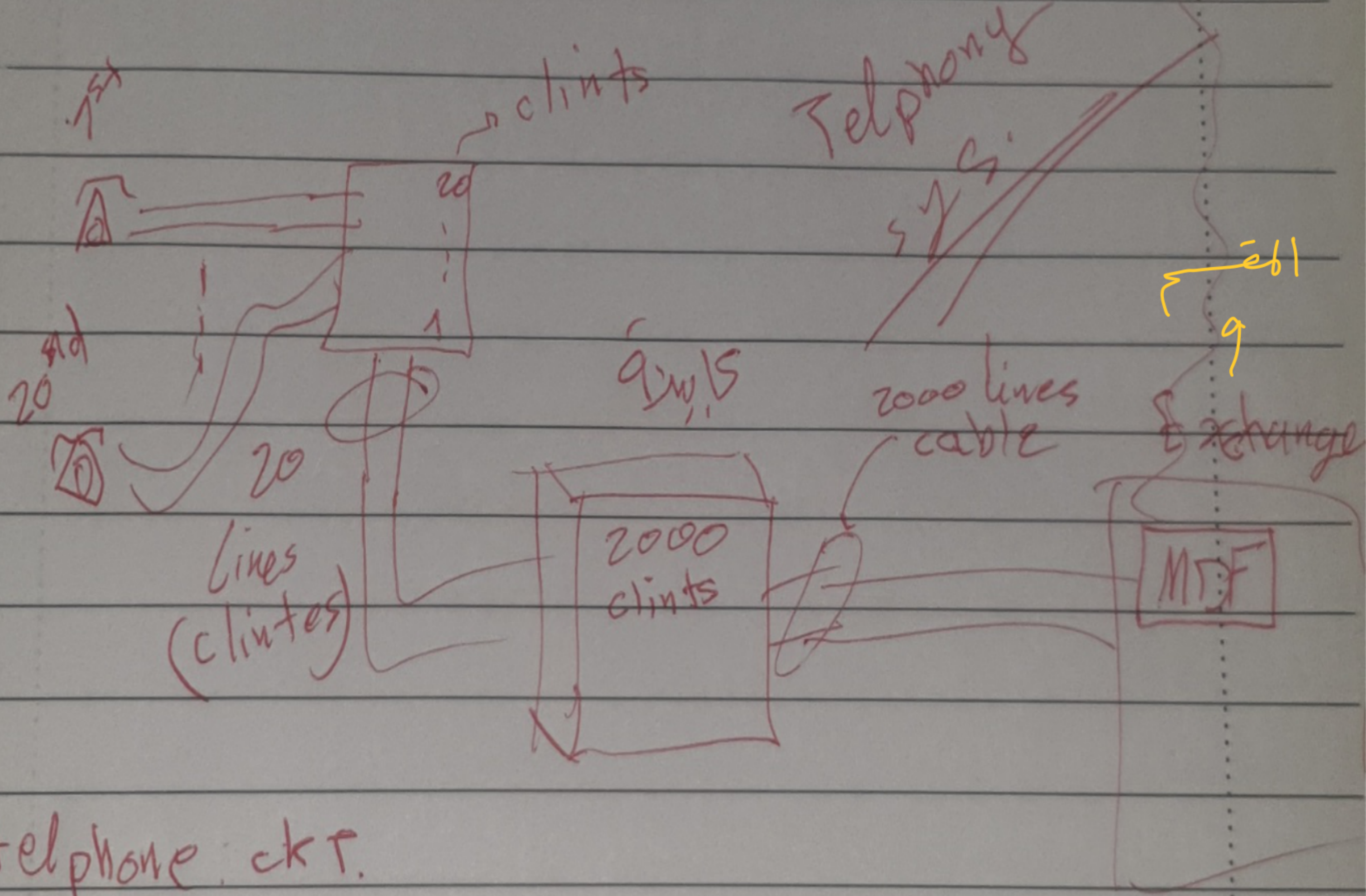
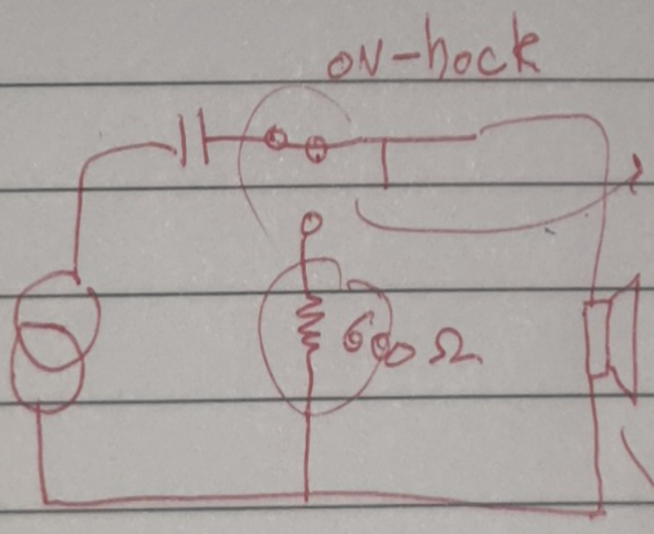
Subject Date No.

main distribution frame (organizing wires)

Land plane sys. :



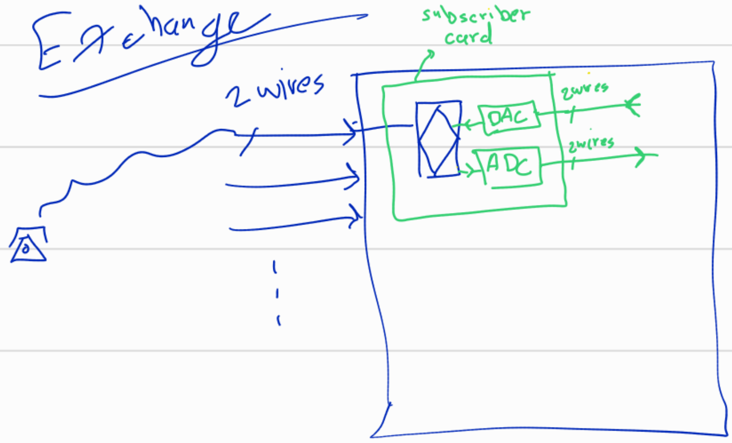
telphone ckt.



when we answer & will connect to 600 Ω resistor

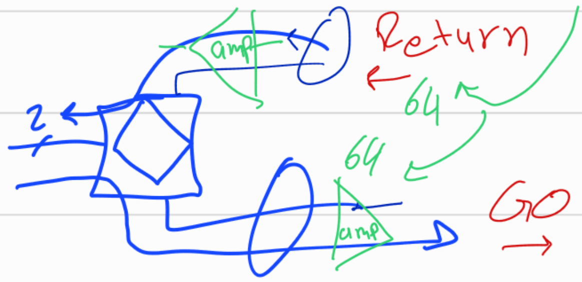
600 Ω
c.y

Exchange



voice quality B.W = 4 kHz, $f_s = 2 * 4 = 8$ kHz
choose 8 bits quantization
data rate $= f_s * 8$ bits
$r_b = 64$ kbps
=> PCM

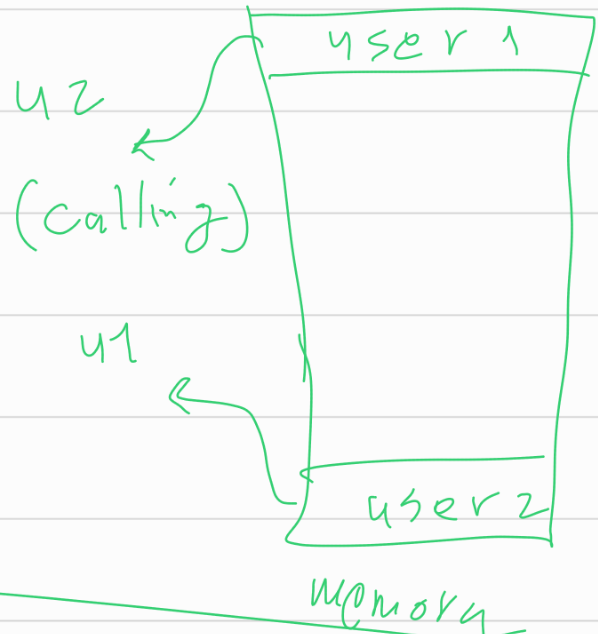
to reduce the losses we increase the cross sectional area



64 + 64 = 128 (two way: duplex)

hybrid Transformer
(2 wires - to - 4 wires)

for long distances we can not increase cross-sectional-area to very high value instead we separate them to Going & Return & attach an amplifier to each



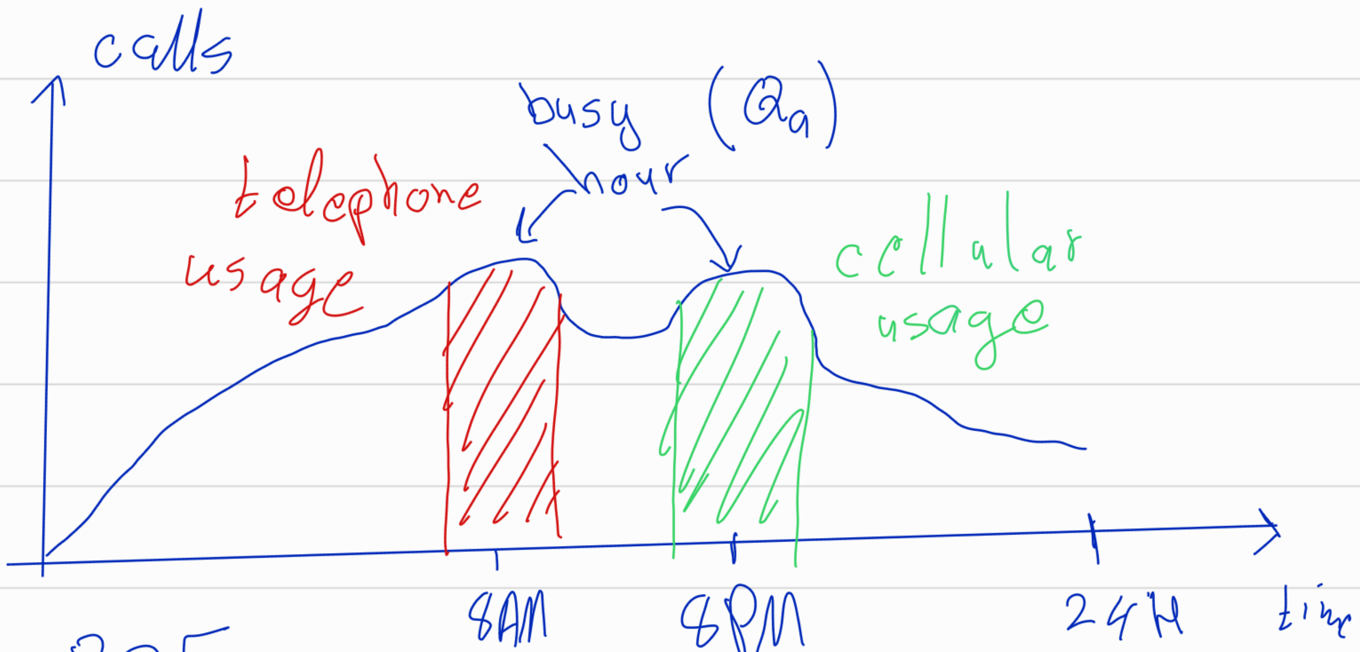
now when u1 is calling u2 a switching process is going switch between u1 & u2, and this process is done by control unit (μcontroller) which is the exchange (well), with help of addresses concept, u1 has an address (linked to telephone number) stored in register.

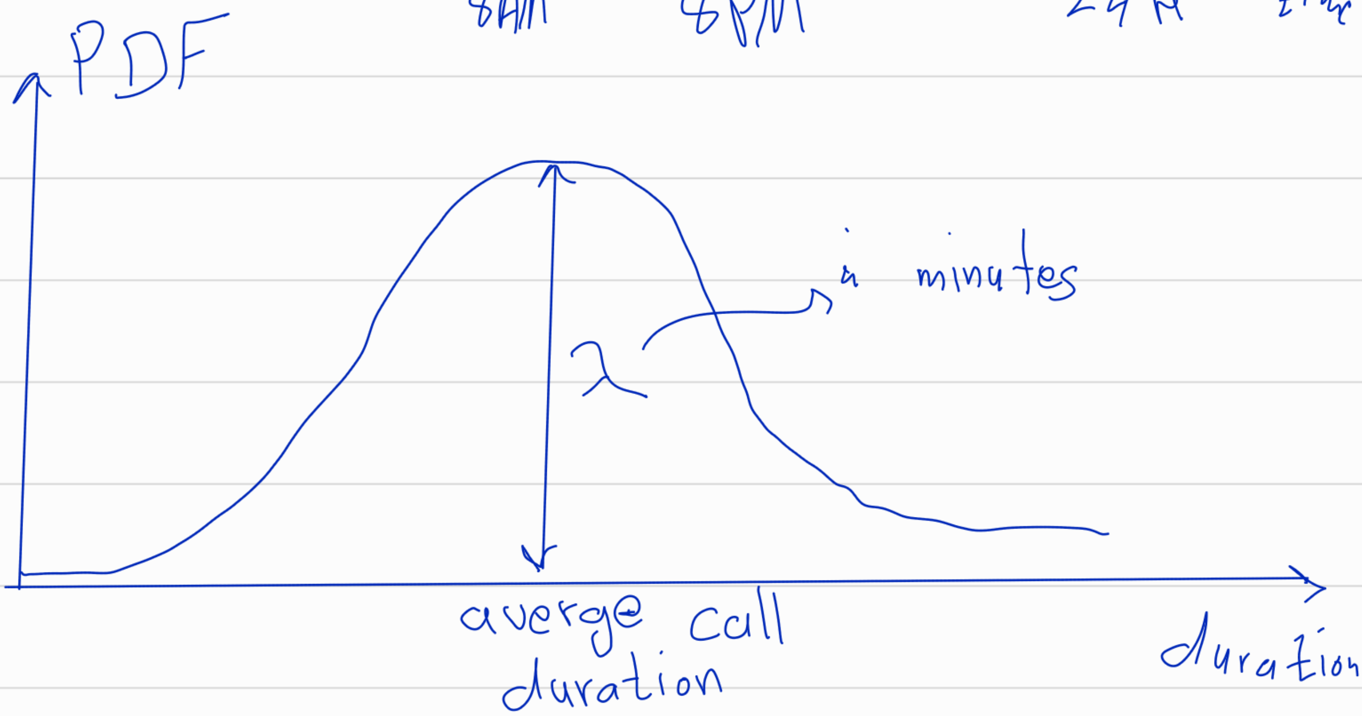
so we need a system (OS) to handle

switching, address storing & fetching, ...
best OS is Unix

embedded linux — for embedded
linux out of unix — for PC

blocking probability :





N_{ch} → numbers of channels, BP(%) → blocking probability

Traffic (A)

$$A = \frac{Q \cdot \lambda}{60}$$ measured in Erlang

since λ in min. we want in hrs

Traffic Theory:

(N_{ch}, A, BP)

Table:

30 channels, λ = 3 min, 1%, find Q_a num. of calls in busy hour

30 ch. & 1% from table

18.59

$$\Rightarrow A = \frac{Q_a \lambda}{60}$$

$$18.59 = \frac{Q_a \, 3}{60} \rightarrow Q_a = 20 * 18.59$$

Q_a = 372 users

total users = Q_T

$Q_a = \zeta\, Q_T$ $\qquad\qquad$ $\zeta \sim (10\% - 15\%)$

so if $\zeta = 10\% \rightarrow Q_T = \frac{372}{0.1} =$

$Q_T = 3720$ users

So, I can serve 372 users at the same time from total users 3720 (10% of all users).

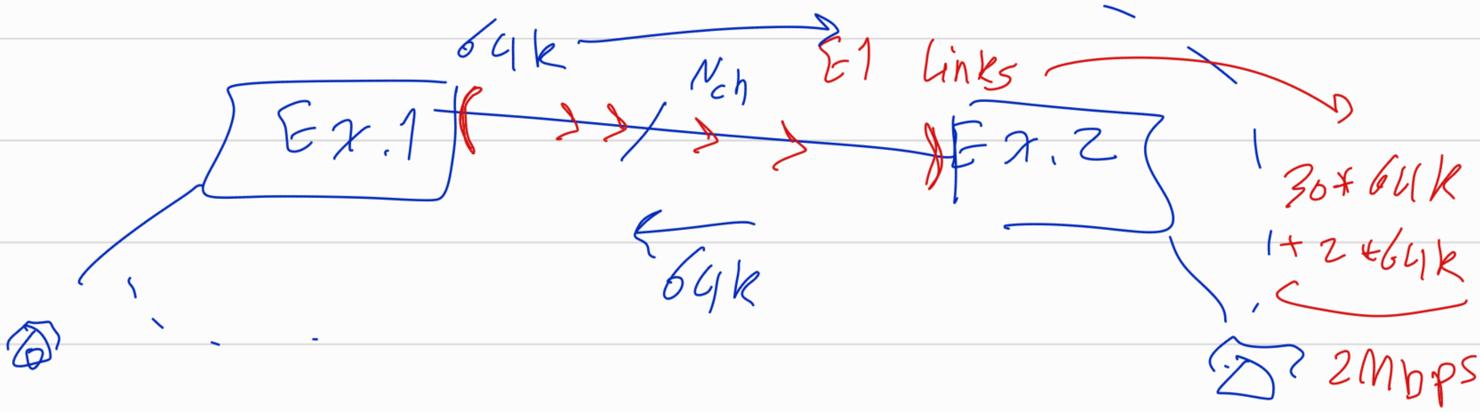
this why I need study the behavior of users (to know how much I need to serve at the same time) The Graph

the 10% from graph is the Busy Hour (Q_a).

Traffic Theory:

(A, BP, N)

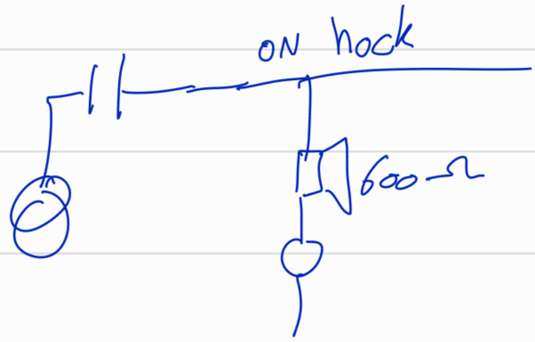
N	1%	2%
15	7.39	8.04
30	18.59	19.64



voice B.W = 4kHz , $f_s = 2f$ = 8kbps
8bit → 64kbps → 1 dir. of voice channel

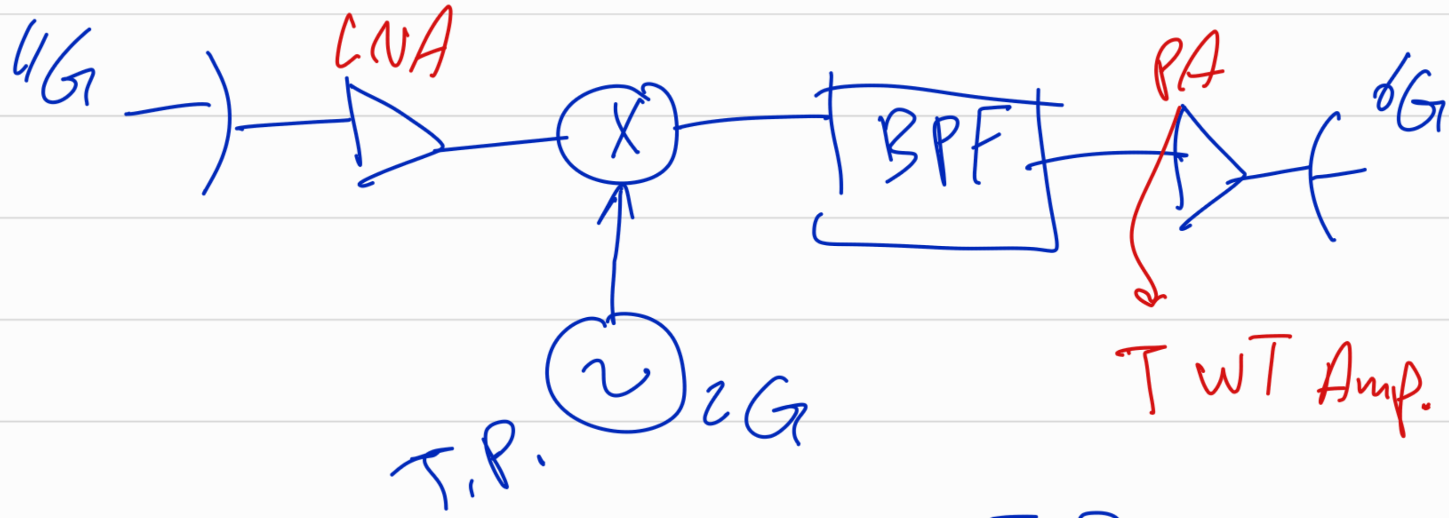
Call setup:

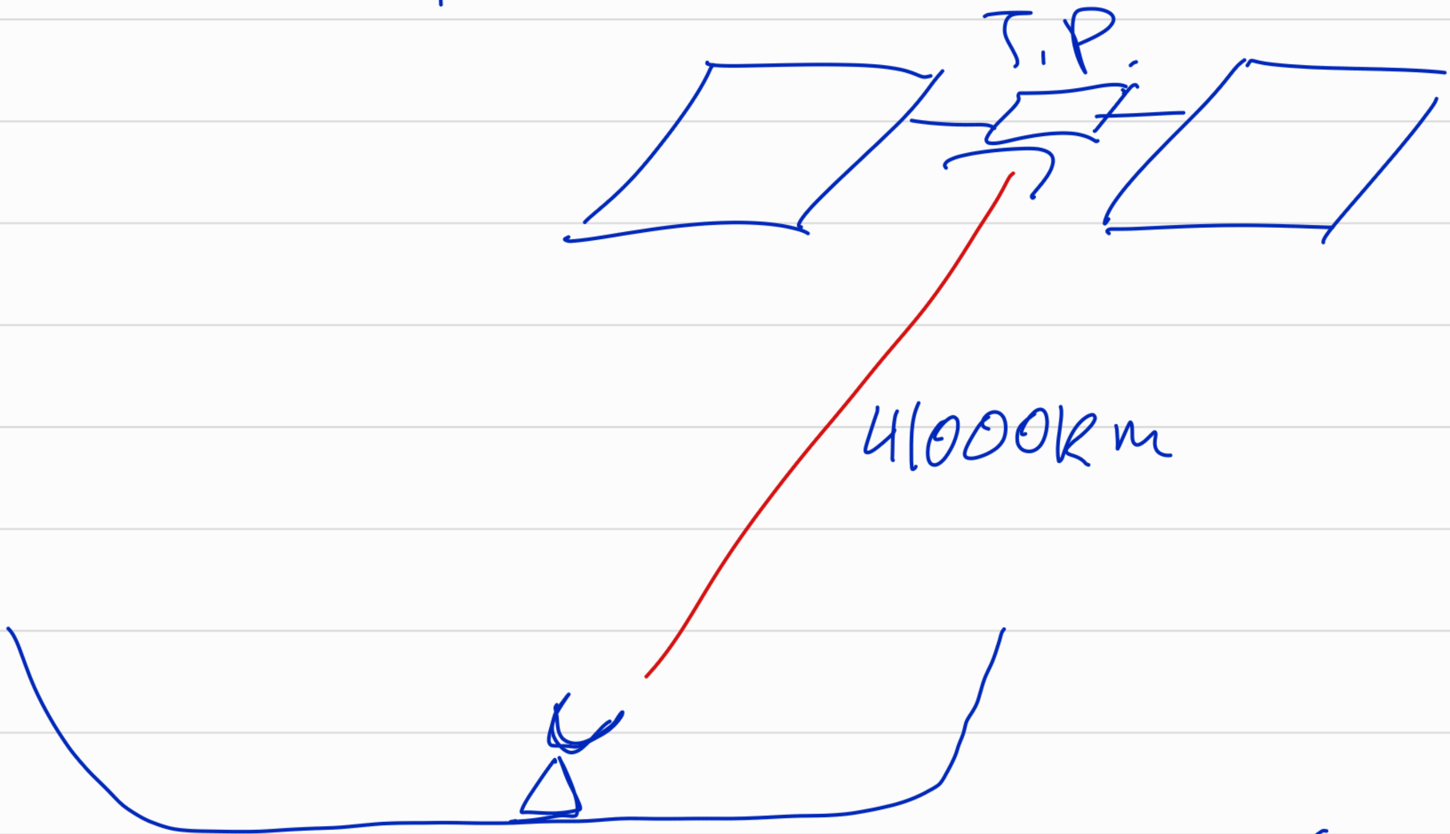
1- off-hock



2- dial
3- dial a number
pre-fix area code 00962
international google it

protocols : SS7, SLIP, IP, ATM
we also we have protocol conversions to communicate each protocol with each other





$$\text{propogation delay} = \frac{82 \times 10^6}{3 \times 10^8} = 273 \text{ msec}$$

---

receiver side has three status in dialing;

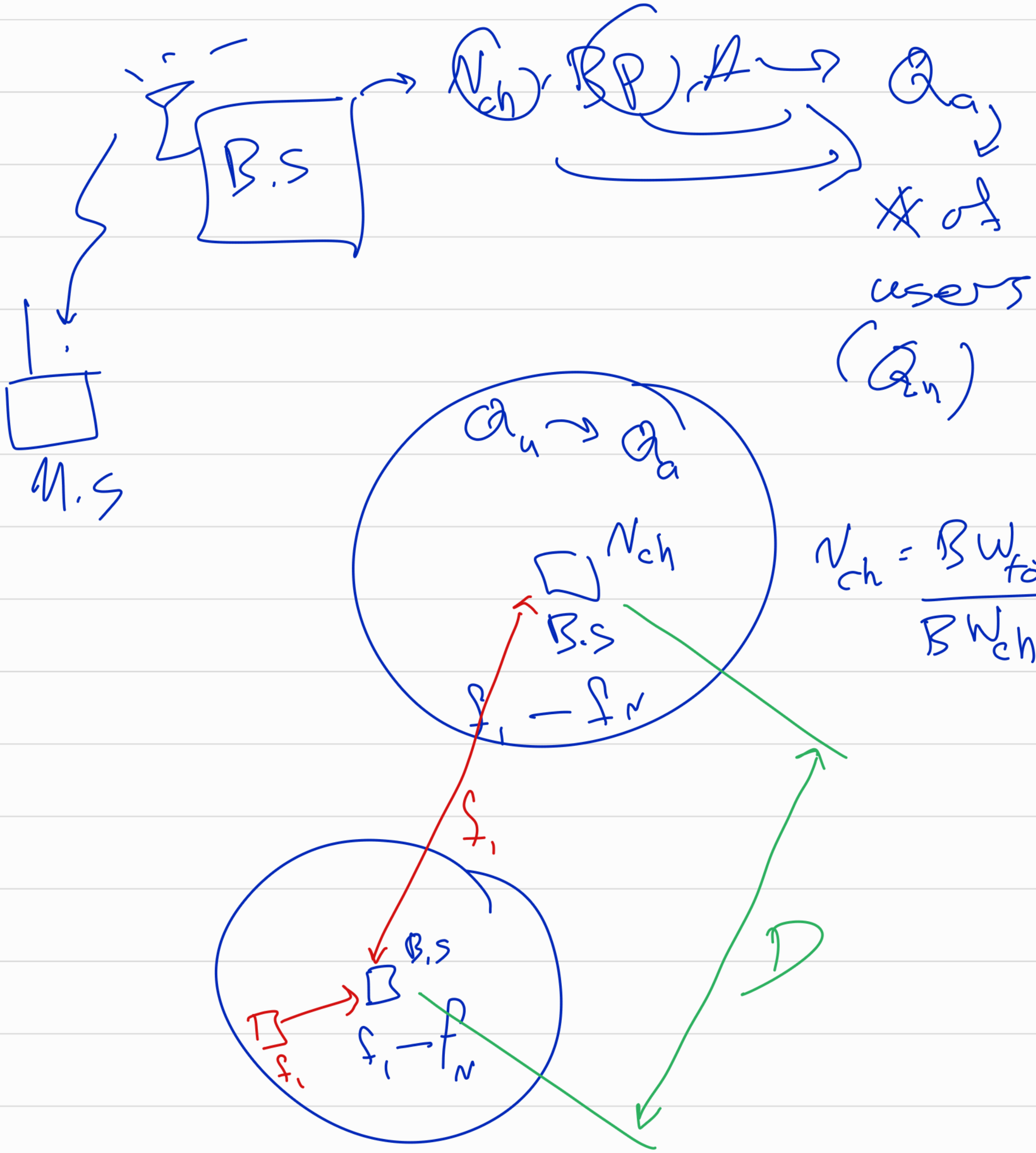
1) ideal: can receive
2) busy: No need to reserve a chann.
3) disconnected: out of service

control signals (commands):

1) XON Xoff
2) SS7

protocols in comm. sys. are commands to perform in some certain sequence.

what is the common between cellular sys. & telephone sys.?



$$N_{ch} = \frac{BW_{tot}}{BW_{ch}}$$

from BER we need to obtain SNR we know as CIR (core channel interference) (our carrier)

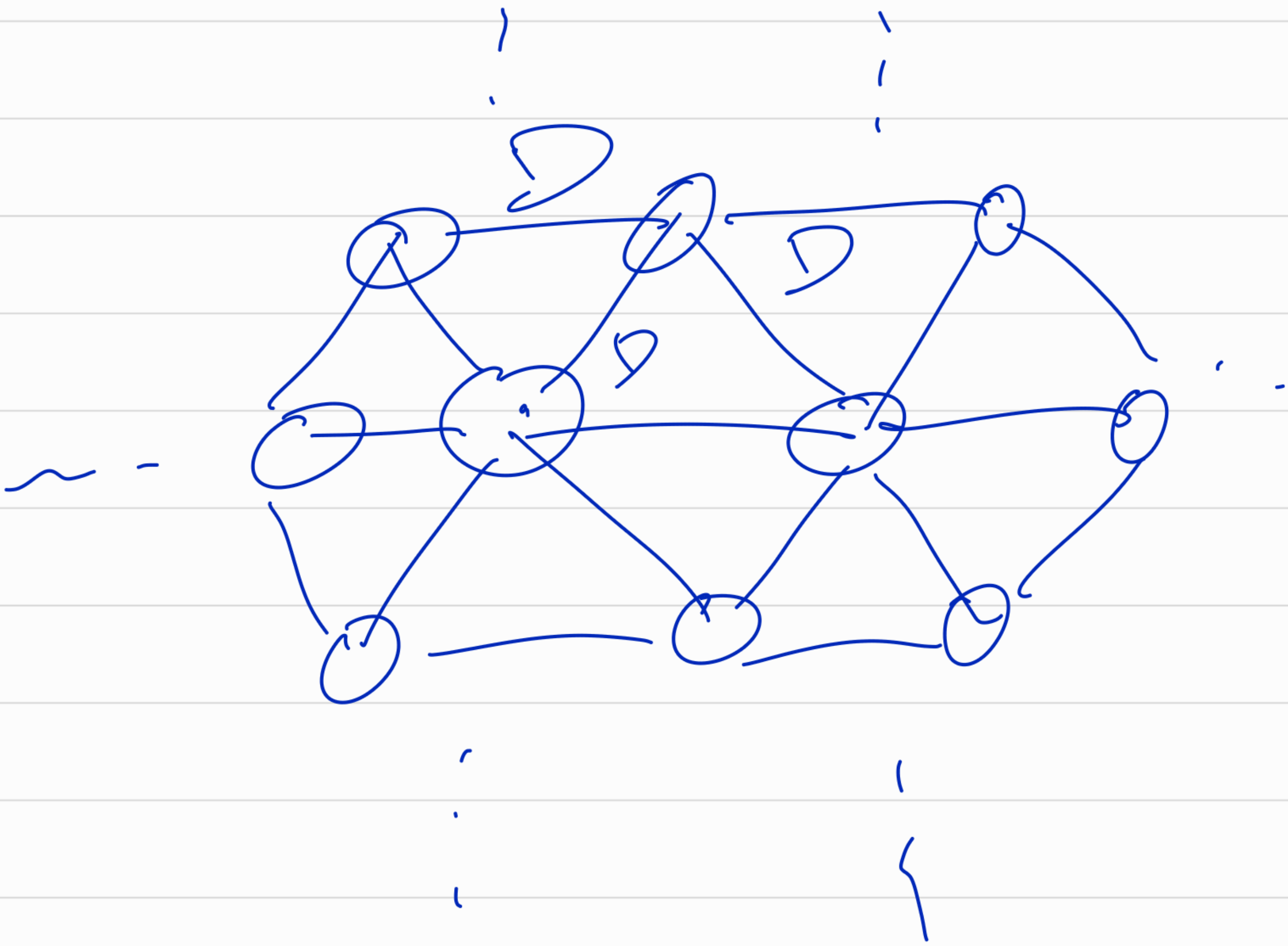
$\frac{C}{I}$ = CIR , SNR = $\frac{P_{signal}}{P_{noise}}$ (recall) we need to consider received power to transmitted power

$$P_r = P_t \, r^{-\gamma} \quad , \; 2 \leq \gamma \leq 4$$

$r^{-\gamma} < 1$

$$\Rightarrow \frac{C}{I} = \frac{P_{t1} \, r^{-\gamma}}{P_{t2} \, D^{-\gamma}} = \frac{P_{1t}}{P_{2t}} \cdot \left(\frac{D}{R}\right)^{+\gamma}$$

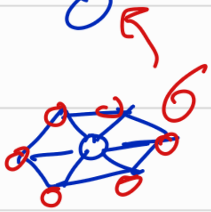
→ we need B.S with same distance D how?



$\frac{P_{1t}}{P_{2t}} \left(\frac{D}{R}\right)^{\gamma}$, we need all p transmitted same to all users

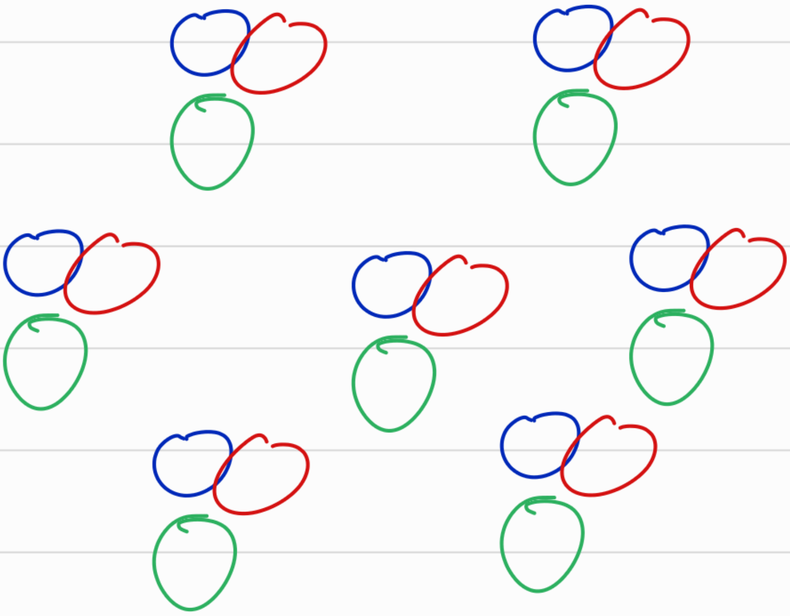
$\frac{P_{1t}}{P_{2t}} = 1$

$\Rightarrow \frac{C}{I} = \frac{C}{\bigcirc} = \frac{(D/R)^{\gamma}}{6}$



BER controlled by modulation

$\Rightarrow \frac{C}{I} = \frac{q^{\gamma}}{6}$, $q = \frac{D}{R}$ = reuse factor



we need k to fill all the space

$$\left(\frac{N_J}{k} = N_{ch.}/\text{cell}\right)$$

$k = i^2 + ij + j^2$ $i, j = 1, 2, 3, \ldots$

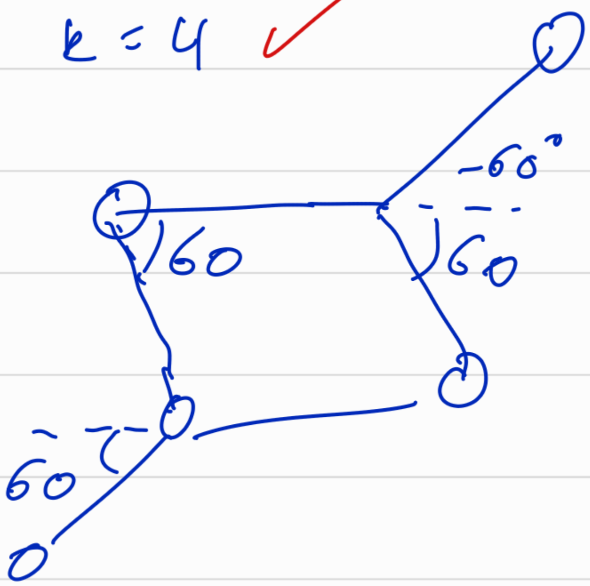
$i = 1$, $j = 1$, $k = 3$ ✓

$i = 1$, $j = 2$, $k = 7$ ✓

$i = 2$, $j = 2$, $k = 12$ ✓

$k = 4$ ✓

Not all k works!



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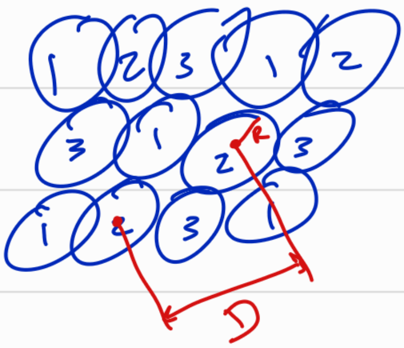
for $k = 3$



every number represents freq. f

$1 \rightarrow f_1$
$2 \rightarrow f_2$
$3 \rightarrow f_3$

$$q = \sqrt{3k}$$

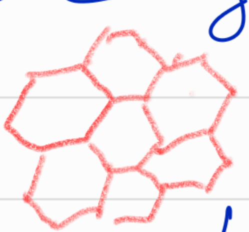
the Less k the more cost we save.

in commu. sys. we have intial cost / run cost

---

limited N_{ch} we need to cover max. number of users

we call these geometry clusters.



γ is area factor

default value of γ is 3

$10dB \rightarrow \frac{C}{S} = 10dB = \frac{Q}{6}$

$\rightarrow q = \sqrt[3]{60} = 3.9$

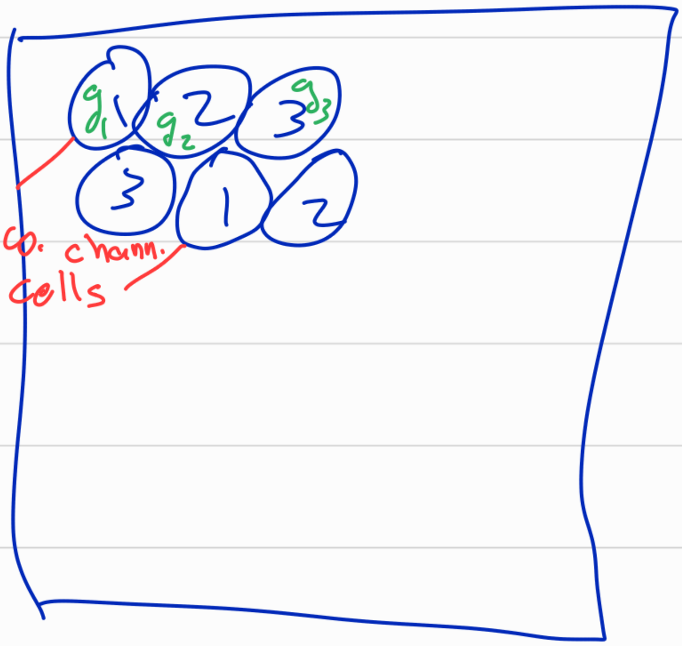
$$k = \frac{3.9^2}{3} = 5.1$$

$\rightarrow$ $k = 7$

---

k diff. types

k is reuse factor



$\frac{D}{R} = q$,

$\frac{C}{I} = \frac{q^{\gamma}}{6}$, $q = \sqrt{3k}$, k different groups of channels.

N_T : total num. of chann.
each cell type will have $N_{cell} = \frac{N_T}{k}$ chann.

---

* to Design of Basic cellular sys. we do the followings:

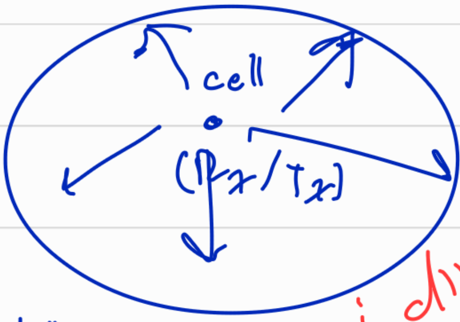
1) Assumption

I) Flat earth

II) users are uniformly distributed.

III) Omni directional cells

2) we study the population demands,



omni dir. cell

I) Traffic generation.

$$A_{Tot} = \frac{Q_0^{Tot} \cdot \lambda}{60} \quad (Er)$$

e.g. 5 M users → I antcipate 10% at busy hour → 0.5 M

$Q_0^{Tot} = 500k$ ⇒ active users

Average Return Per User **ARPU**

كم يستطيع المستخدم دفع للشركة
شهرياً (الاردن تقريباً "10JD")

---

ex. 1% BP, λ 2min (average call duration)

$$A_{Tot} = \frac{Q_0^{Tot} \cdot \lambda}{30} = \frac{500,000}{60} \times 2 = 16.6 \text{ KEr}$$

(16.6 KEr → total)

for each cell separatly

let $N_{Tot} = 180$

case I : k = 3

$q = \sqrt{3k} = 3$, $\gamma = 3$ (default)

$N_{cell} = \frac{180}{k} = 60$ at 1% → $A_{cell} = 43.16$ (from table)

total num. of cells $= \frac{16.6k}{43.16} = 384.01$

⇒ **385 cells** even if 384.01 → 385 to cover it all

for 2% $A_{cell} = 44.8$

→ $\left\lceil \frac{16.6k}{44.8} \right\rceil = 371$ cells

385 - 371 = 14 cells not covered → so not worth it, we stick with 1%

summary: with 2% I saved 14 cells, but customer satisfaction also is lost for some users → so I choose 1% BP. to cover more, beside 14 cells is not that cost saving, → 14 cells might cover 1000 or 2000 users → NOT worth saving.

$\rightarrow \frac{C}{I} = \frac{q^{\gamma}}{6} = \frac{3^3}{6} = 4.5$

in dB $\quad 10\log_{10} 4.5 = \boxed{6.53\ dB}$

Case II : k = 4

$q = \sqrt{12} = 3.46 \qquad \frac{C}{I} = \frac{3.46^3}{6} = \boxed{8.4\ dB}$

$N_{cell} = \frac{180}{4} = 45 \rightarrow \boxed{A_{cell} = 30.67}$ at 1%

Total num. of cells $= \left\lceil \frac{16.6k}{30.67} \right\rceil =$ 542 cells

---

Case III : k = 7

$q = \sqrt{21} = 4.58 \rightarrow \frac{C}{I} = \boxed{12.05\ dB}$

$N_{cell} = \frac{180}{7} = 25.71$ $\rightarrow$ 25 $\Rightarrow 25 * 7 = 175$

$\hookrightarrow$ 26 $\Rightarrow 26 * 7 = 182$

but I have only 180 ch. !

$\rightarrow$ I discard 26 & choose 25

& I distribute the 5 on the 25 cells

1	2	---	7
25	25	---	25
1	1	1 1 1	

5 → (first cells)

so we will have

2 → 25 ch. $A_{25} = 14.72$

5 → 26 ch. $A_{26} = 15.49$

$$\hookrightarrow A_{avg.} = \frac{(14.72 * 2) + (15.49 * 5)}{7} = 15.27 \text{ Er}$$

$$\left\lceil \frac{16.6k}{15.27} \right\rceil = 1088 \text{ cells}$$

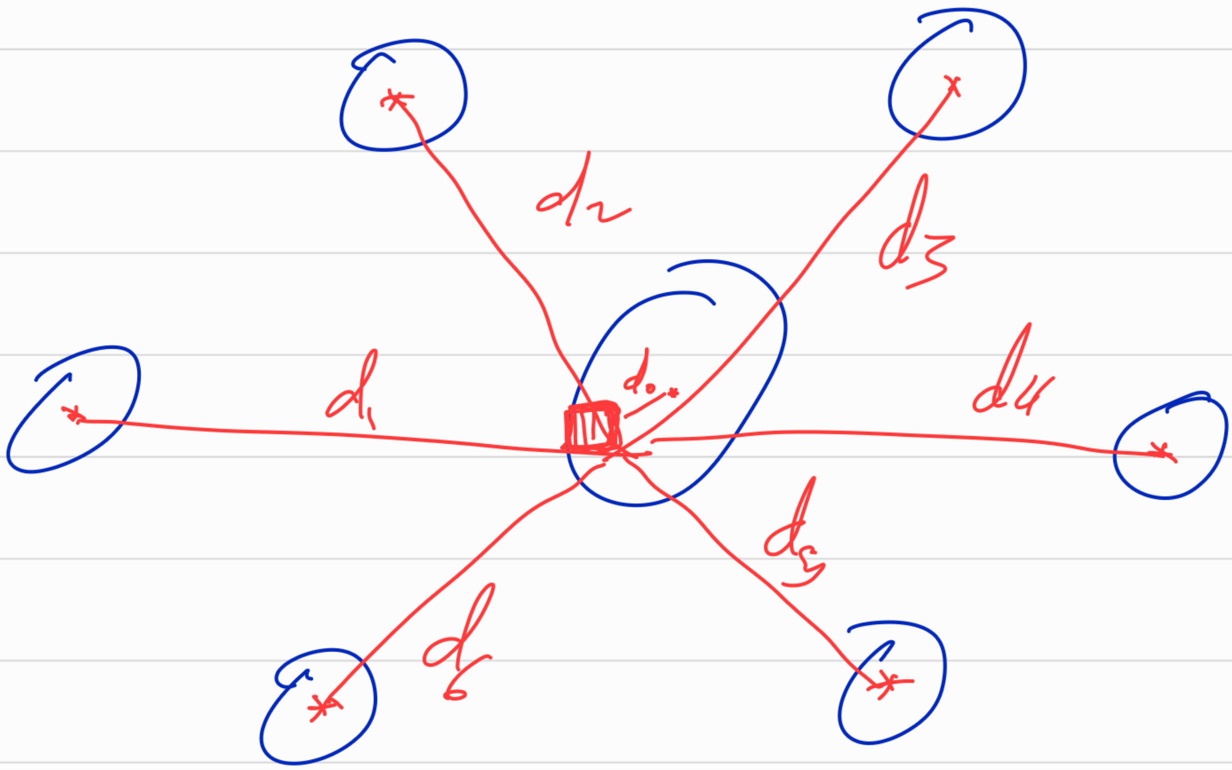
if I can do channel coding & modulation tech., which will give me same BER even if $\frac{C}{I}$ was 6.53 dB

in GSM this was not working → 9.5 dB at least

Cellular
04:37

(dB)

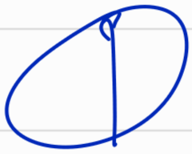
K	C/I	Total cells
3	6.5	385
4	8.4	542
7	12	1088



$$P_r \propto d^{-\gamma}$$

$$\frac{C}{I} = \frac{d_0^{-\gamma}}{\sum_{i=1}^{6} d_i^{-\gamma}} = \frac{R^{-\gamma}}{\sum D^{-\gamma}} = \frac{(D/R)^{\gamma}}{6}$$

sectorization :

n = 2  n = 3 

n = 4  n = 8 

directional Antenna Gain > 1

$$\frac{C}{I} = \frac{q^{\gamma}}{\left[\frac{6}{n}\right]}$$

	n = 1		n = 2	
k	C/I	Total cells	C/I	total cells
3	6.5	385	9.5	449
4	8.4	542		
7	12	1088		

$N_T = 180$ — from table

$\frac{180}{3} = 60 \rightarrow A_{cell} = ??$

(30 | 30) $\rightarrow A_{sec} = 18.59,\ A_{cell} = 18.59 \times n$

$A_{cell} = 37.18\,E$, $\frac{C}{I} = \frac{q^{\gamma}}{\lceil \frac{6}{n} \rceil} = \frac{3^3}{\lceil \frac{6}{2} \rceil} = 9 \rightarrow$ **9.5 dB**

($\lceil \frac{6}{2} \rceil = 3$)

total cells $= \frac{16.6k}{37.18} =$ **449 cell.**

n = 3

K	C/I	total
3	11.3	507

$N_{sec} = 20$ ch.

$A_{sec} = 10.97$

$A_{cell} = 10.97 * n$

$A_{cell} = 32.91$

$\frac{C}{I} = \frac{3^3}{\lceil \frac{6}{3} \rceil} = 13.5 \rightarrow$ **11.3 dB**

total cells $= \lceil \frac{16.6k}{32.91} \rceil =$ **507 cells**

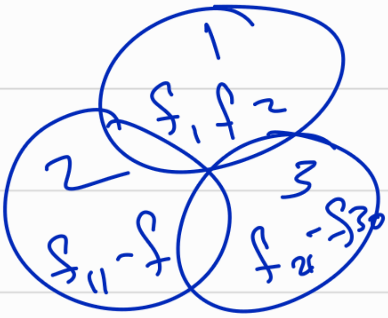
---

so as a standard we configured a configuration

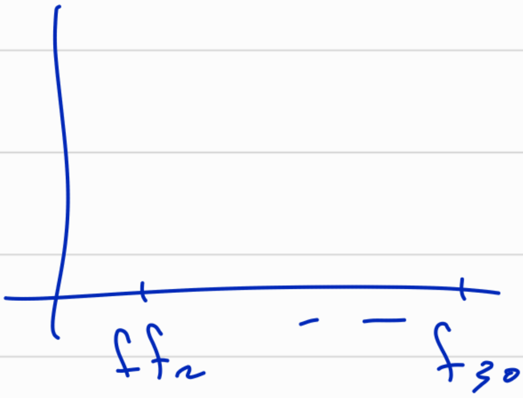
k x n configuration

3 x 3 → default in exams

freq. plan:



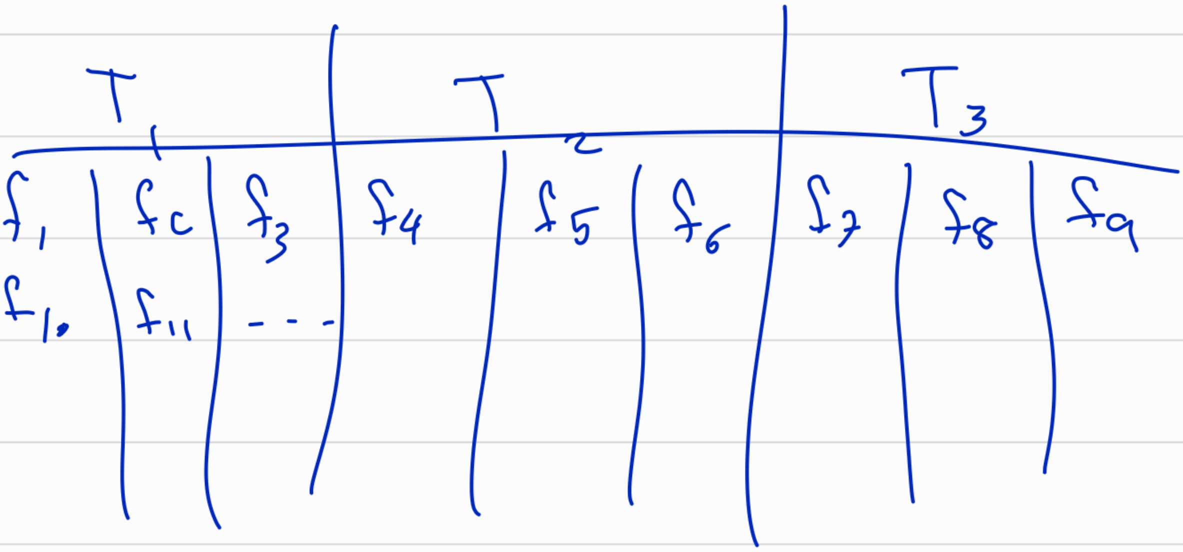
adjacent chan. interference



omni direction $k = 3$

T_1	T_2	T_3
f_1	f_2	f_3
f_4	f_5	f_6
		⋮
		f_{30}

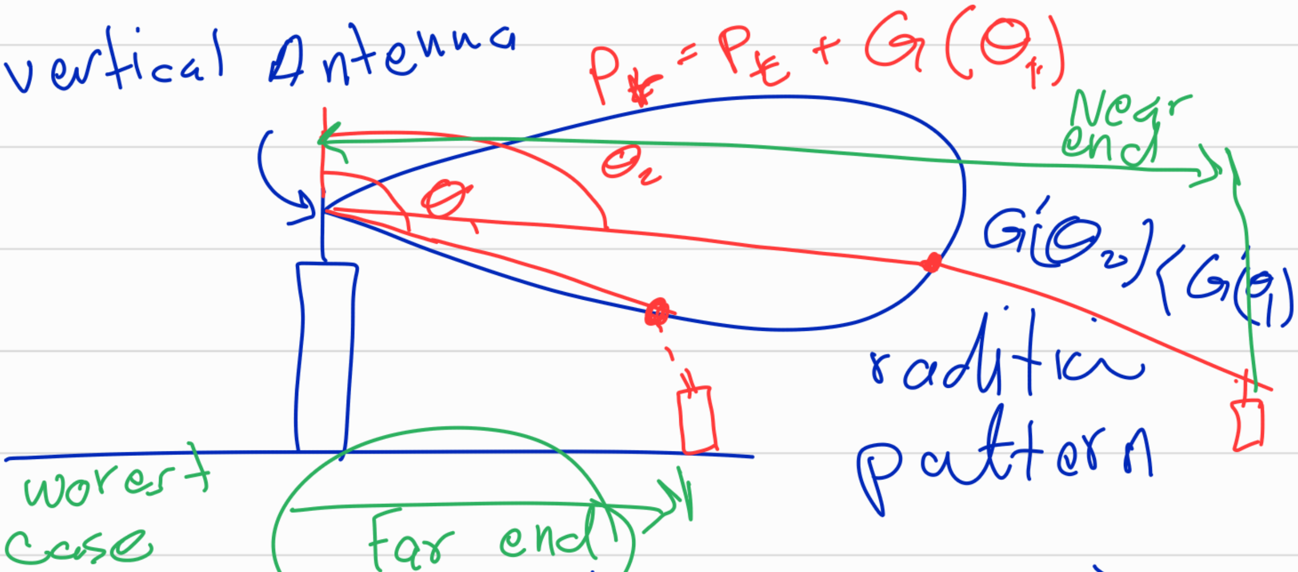
since we have a control design for diff. sectors in the same cell we can isolate the signal of each others



here I reduced adjacent channel interference

Basic Design:

- Flat earth
- uniform user distribution
- k x n (3 x 3)

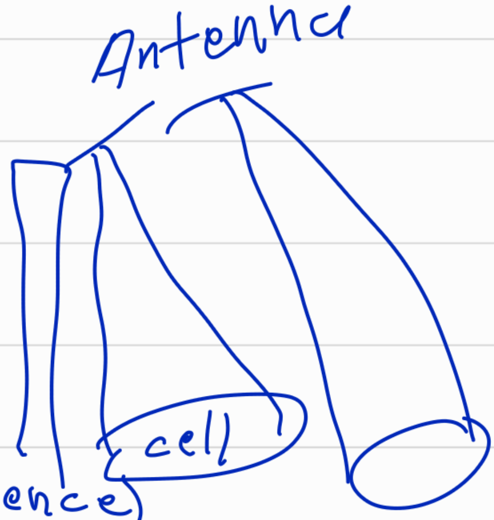


$$\frac{C}{I}\Big|_{new} = \frac{C}{I}\Big|_{old} + \left(G'(\theta_1) - G(\theta_1)\right) + \left(G(\theta_2) - G'(\theta_2)\right)$$

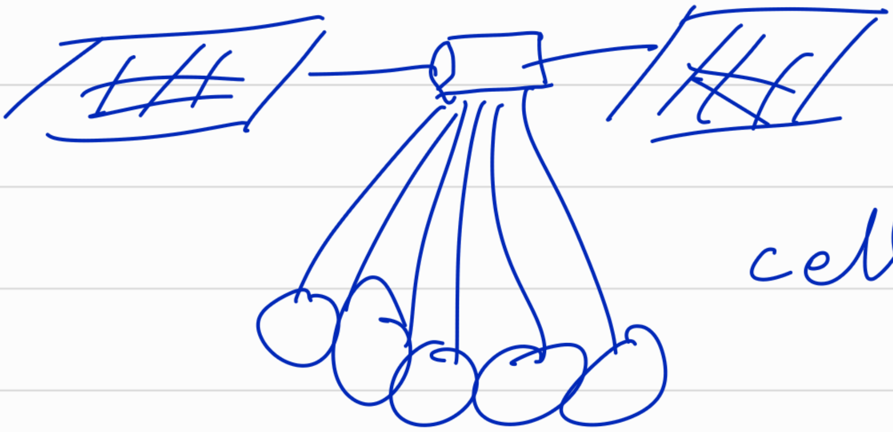
$\frac{C}{I}$ enhancement

1- Down tilting

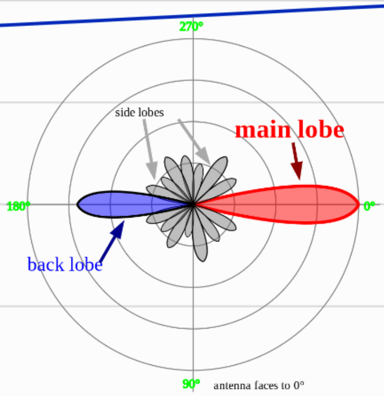
is to aim main lobe of the vertical plane radiation of an antenna below or above the horizontal plane

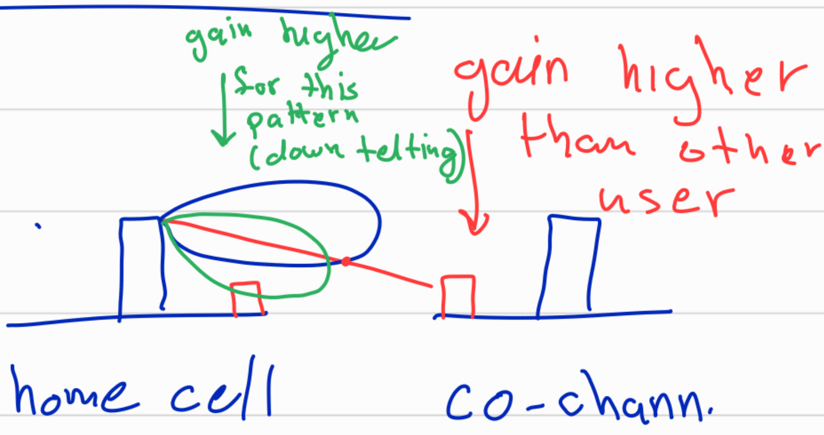


I use antenna to cover a specific spot (reduce interference)



cellularating





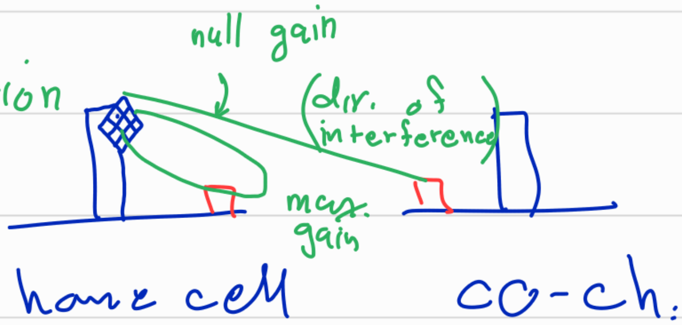
→ $I \downarrow$ $C \uparrow$

$\Rightarrow \frac{C}{I} \uparrow$

using telting

another approach → smart antenna (array)

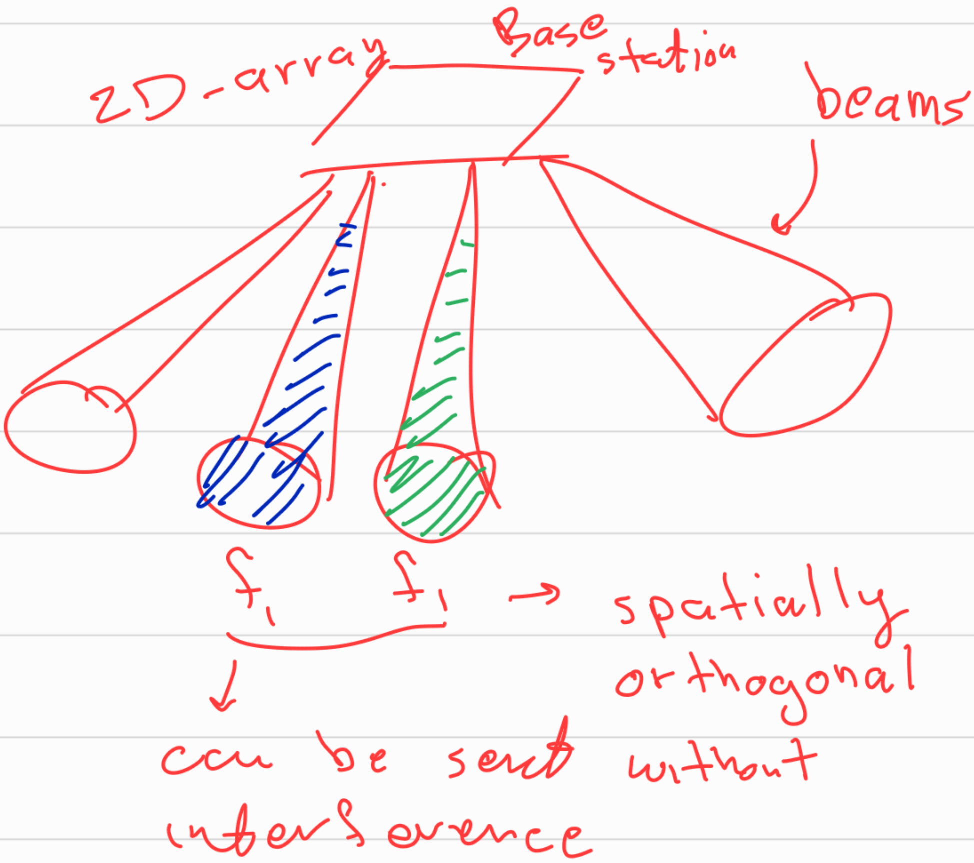
has null in the direction of I, & max in c dir.



Smart Antenna: is an antenna with smart signal processing algorithms.

used to identify spatial signal signature, & use them to calculate beam forming vectors to track & Locate the antenna beam on mobile/target.

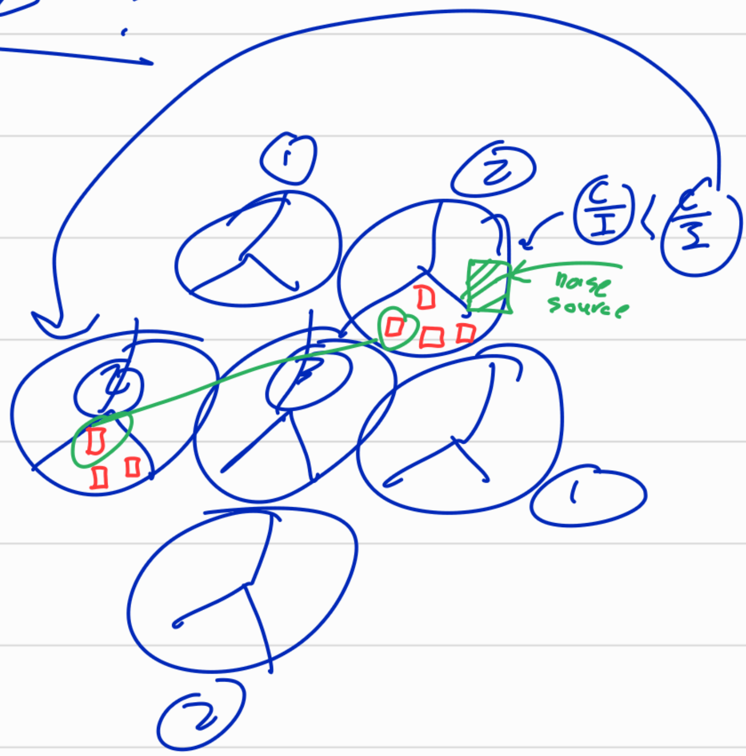
Smart Antenna multi-beam



$\frac{C}{I}$ enhancement :

at busy hour all channels are active.

sys. busy → congested



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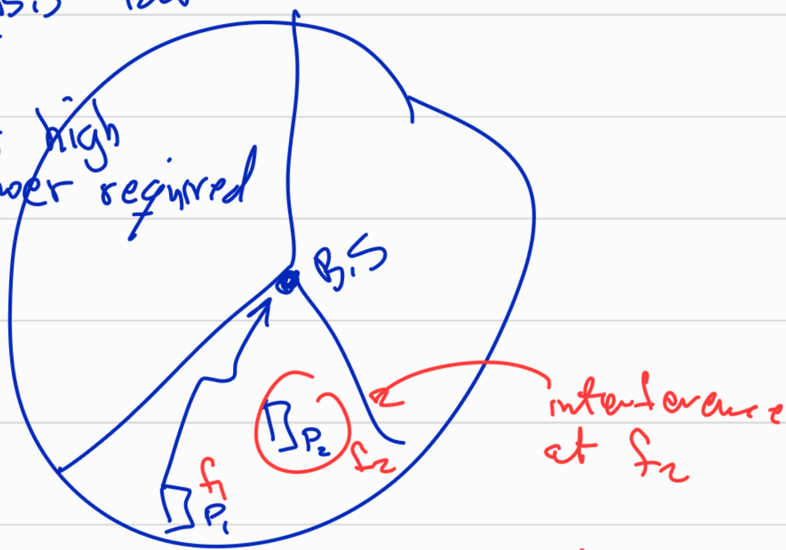
power control
→ near B.S low power
→ far B.S high

→ near user T_x less power required



sol. Frequency Hopping $P_1 > P_2$ $(\frac{C}{I})_2 < (\frac{C}{I})_1$

(F H) → all users change their channel is synchronized manner such that everyone will use (f_2) for a fraction of time lowest $\frac{C}{I}$ controlled by the network

1bit ON, OFF

System operations:

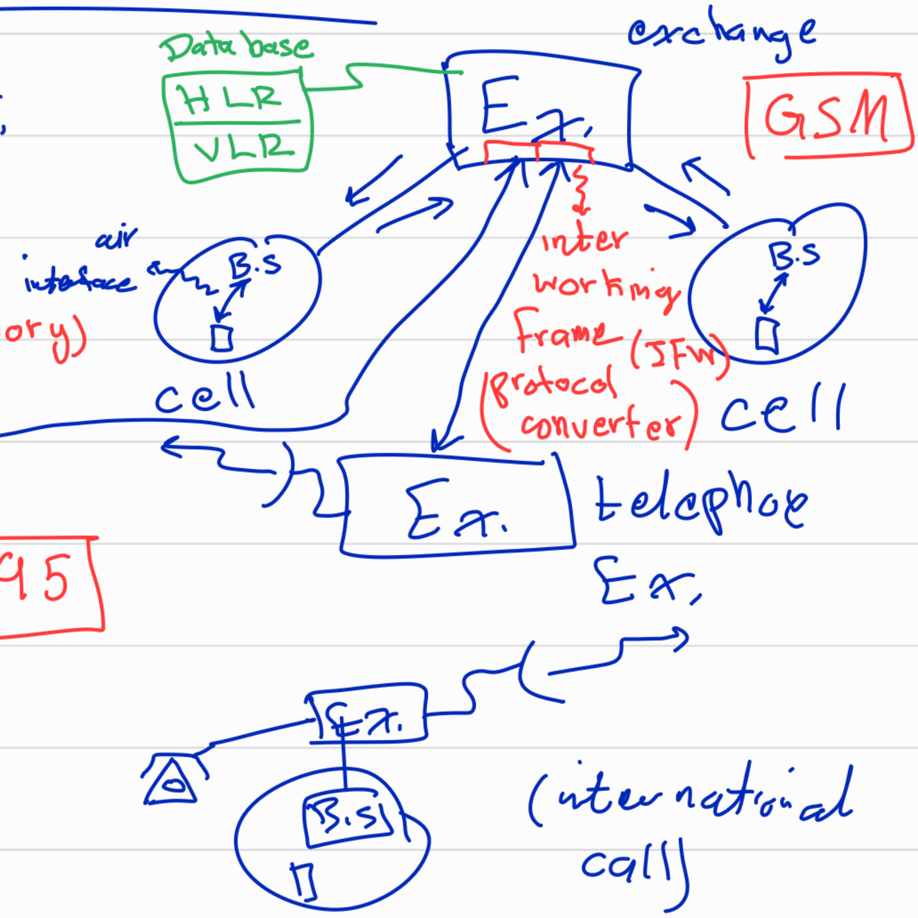
=> call setup

* Air Interface.
* Transmission.
* Switching.
* CPU & Net.
* value Added services (like ringing, GPS, ...).
* Monitoring and control (not in telephone but in cellular is important also for power control)

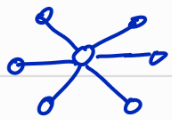
operations:

HLR = Home Location Register (memory) → local users

VLR ≡ visitor Location Register → Foreigner users



HLR (SIM card)
→ status (busy, Idle, off, out of service)
→ personnal VID, EIN, ..., state of billing
did I paid my subscribtion bill?
→ policy (Accounting) ①
→ Location
- cell/sector? (LAC) ②
↳ what Ex.? in telephone sys.
- ③ P_r from home (max power)
- + 6 neighboors → ordered according to max. power



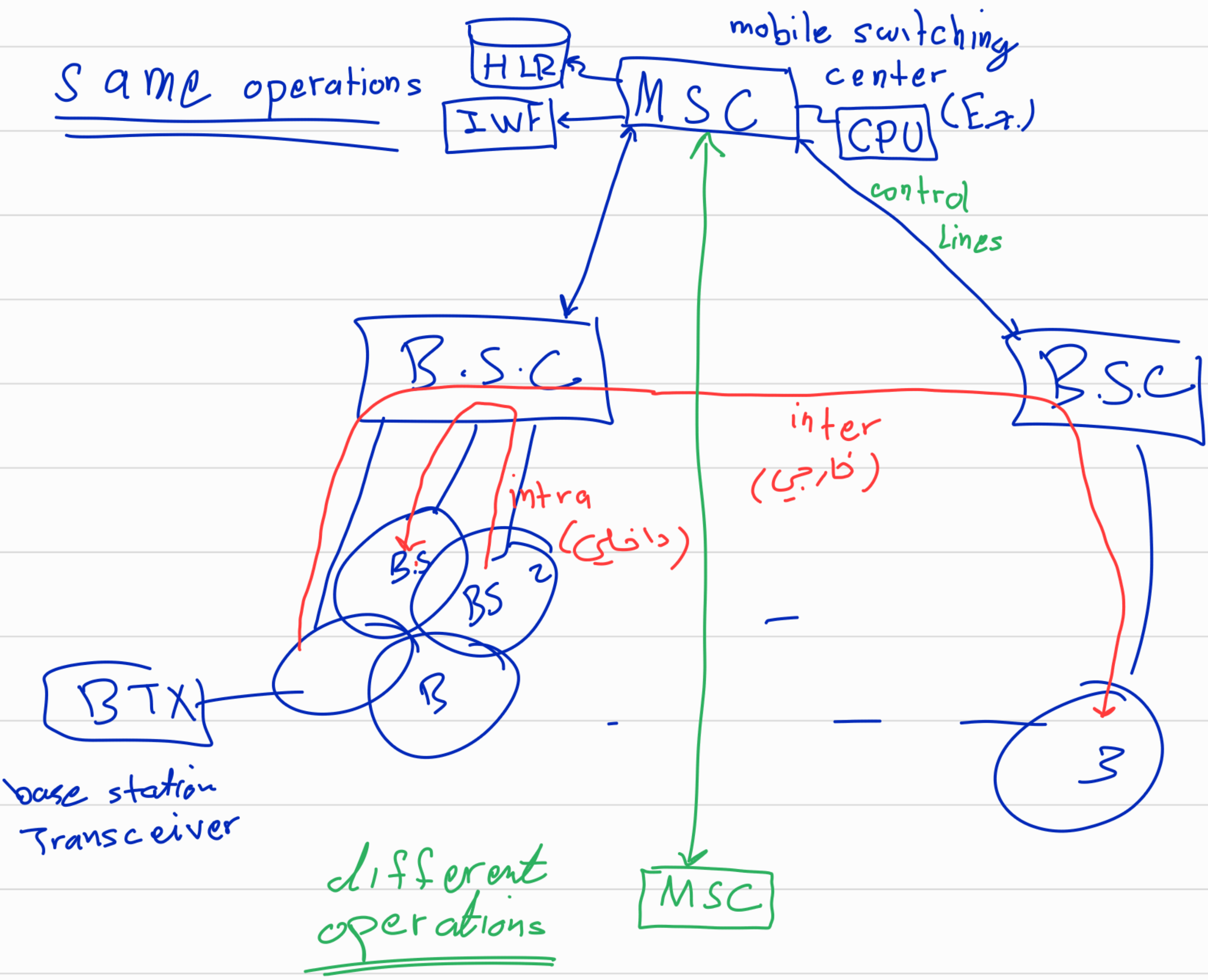
1- max pow.
2- Less max pow.
3- Less Less max pow.
⋮
7- Lowest pow.

if I am on the move P_r is max in home
max P_r decreases until I cross the cell boarder
Hand over is done (HO)
when the other cell has $P_r > P_r$(home) I receive from B.S all this is stored in HLR (address of at what cell/sec)

* as mobile cell phone I receive power from all B.S (7 cells) the cell I am in max power, the other 6 cells the near are the more power from the far.

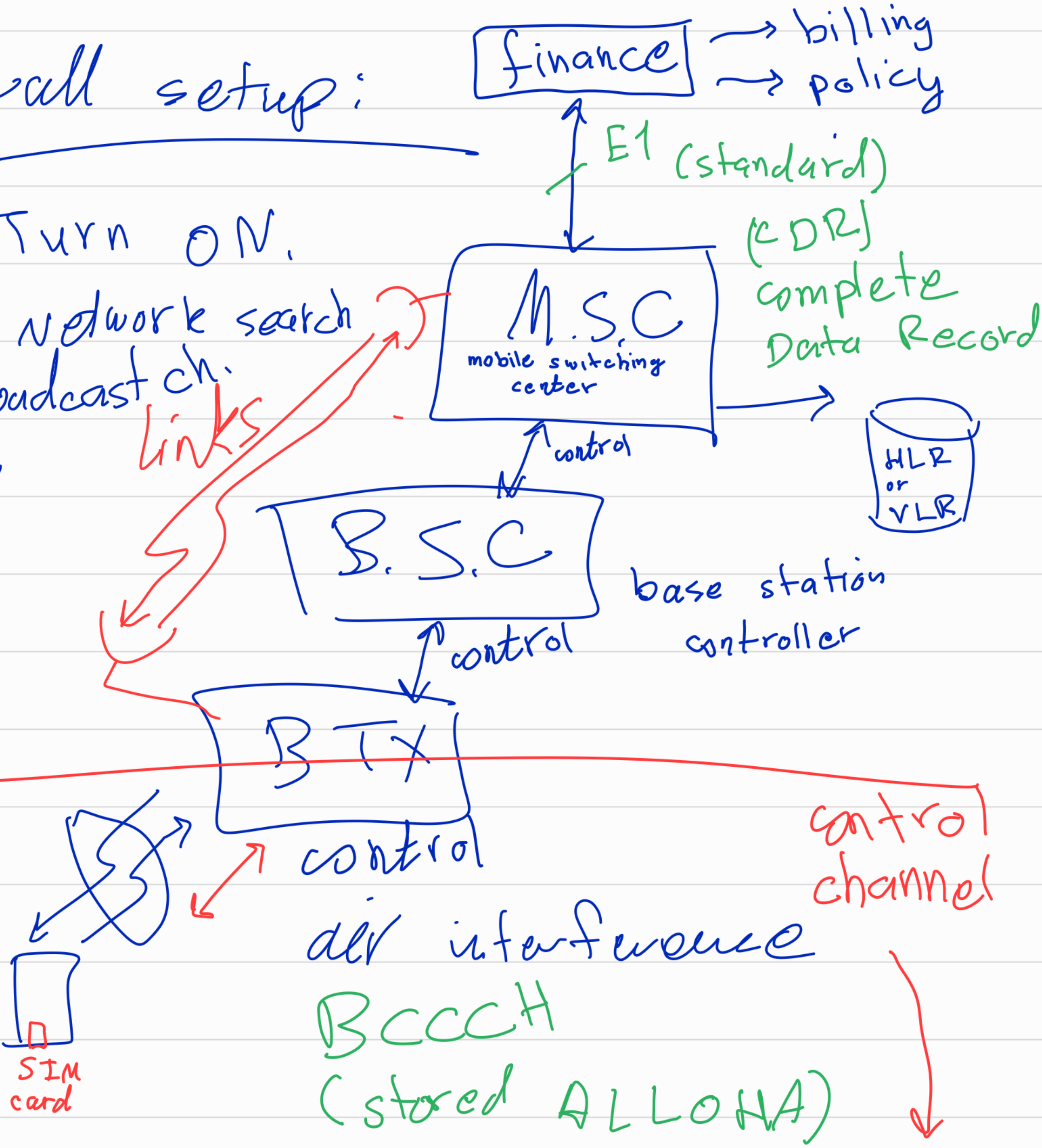
---

hard hand over is when I am in a cell does not has same freq. of the caller every B.S controller controls 32 cells



Call setup:

- Turn ON.
  - network search
  broadcast ch.

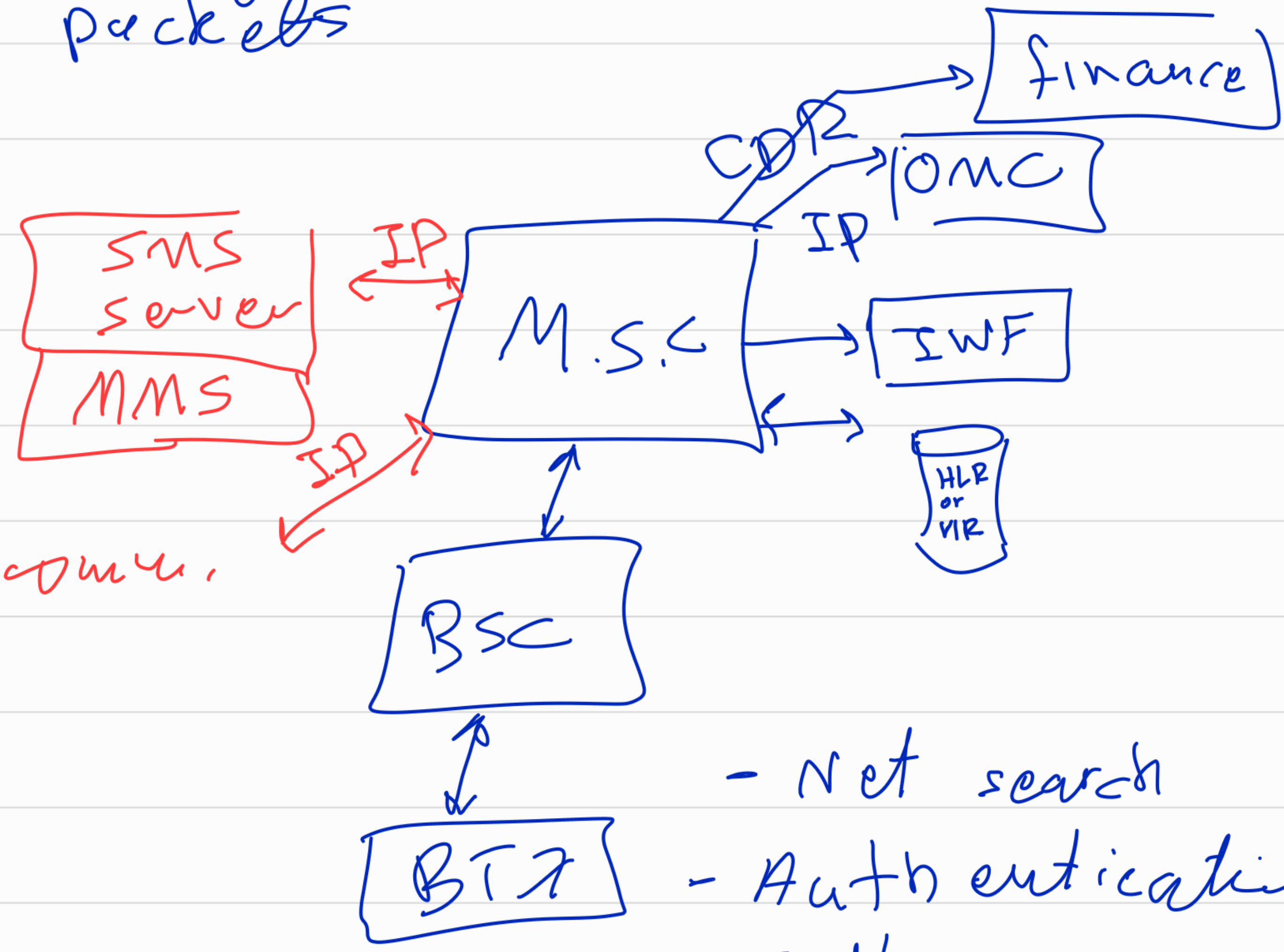


to send & receive packets between Network & mobile

- Authentication

→ Idle - state
(Loc - update)
P + H
+ 6 neighboors

* we can send SMS, MMS (when we reach Idle-state) through GSM, but it is limited packets



- Net search
- Authentication
- Idle
  * Establish a call
- Number dial

→ BCCH → MSC

BSTN Telephone protocol

after dialing → check status
if not Idle → send to caller is not Idle → out range
→ turned off
→

Idle ✓ → sends ringing messages to other side, meanwhile the caller keeps getting status

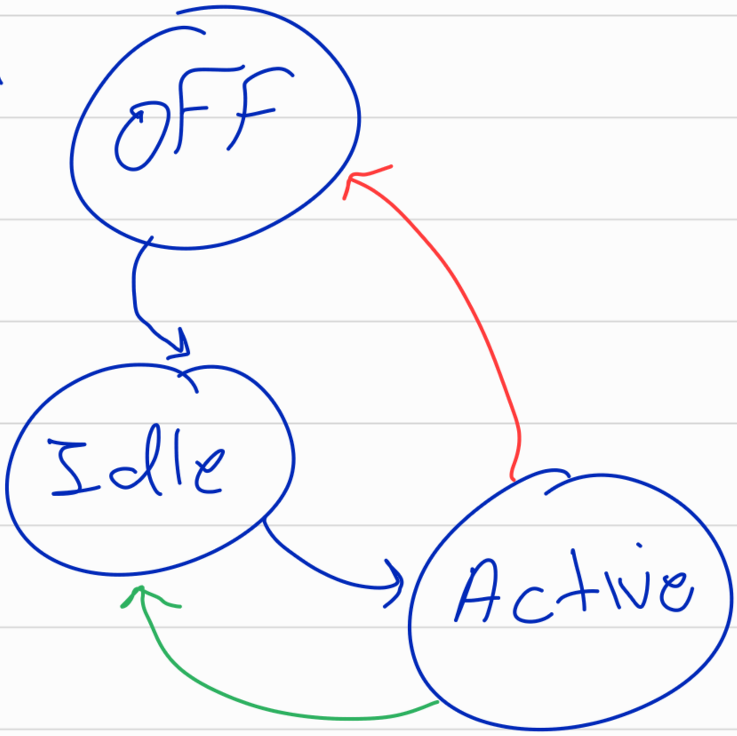
when answered → sends message call accepted → achieve voice channel

- active status & achieve voice channel

when any side ends call, call message is sent to drop (voice channel) => Net sends control data

all messages established on voice channel

Call setup:
call state



all possible
scenario

Ex. Design a cellular sys. with 270 channel and total active users at busy hour = 500k
BP = 1%, λ = 2 min, one control channel / second

$$A_T = \frac{500k * 2}{60} = 16.67 \text{ Er}$$

→ ** sectors [3X3] default value

$N_T = 270 - 9 = 261$ 9 sec } → 1 control channel

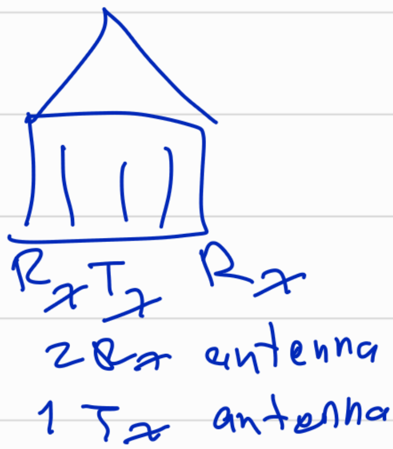
$$N_{sec} = \frac{261}{9} = 29 \text{ ch/sec}$$

if per cell I
remove 3

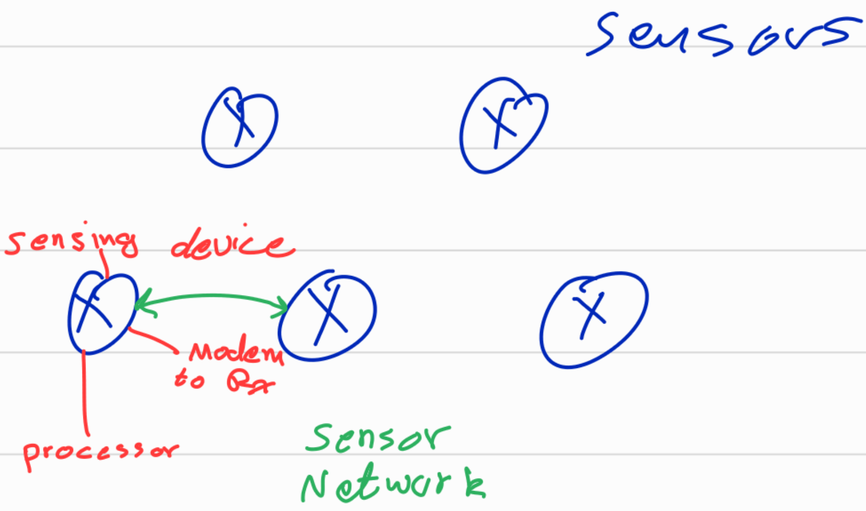
$A_{sec} = 17.81 \rightarrow A_{cell} = 3 * 17.81 = 53.43$

Total num. of cells $= \frac{16.667k}{53.43} = 312$ cells

29 voice + 1 control
in each sector



wireless sensor network:



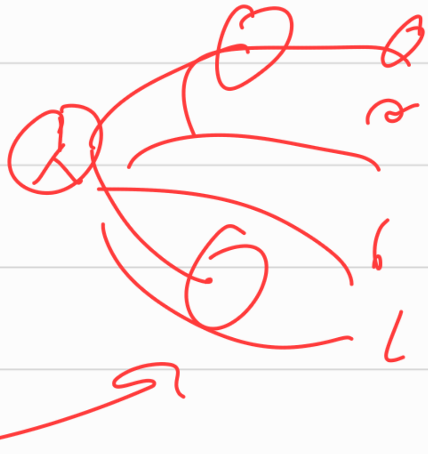
RSSI

recei signal strength indicator

coverage:

$$\frac{C}{I} = \frac{P_{sig}}{\sum P_I + n}$$

$$\frac{C}{I} \approx \frac{C}{2I + 0.6I + n}$$



1 - Time average: percentage of time you establish a call at any point of the network regardless of Location, depends on reliability of the Network,
reliability depends on several factors like cont. of operating, sys. cooling, ...,

2 - Space average, we need to study

* $P_r \geq$ Receiver sensitivity [acceptable P_r (min)]
* $\frac{C}{I} = \frac{P_r \text{ cell}}{\sum I_{others}}$

$P_r(\text{space}, \ldots) = f(?)$ R.V

C is my signal
I is others signal (unwanted)

Hot Topic → Predictive Maintance
→ predict the equipments & devices damages before actual damage occurrs.

space coverge :

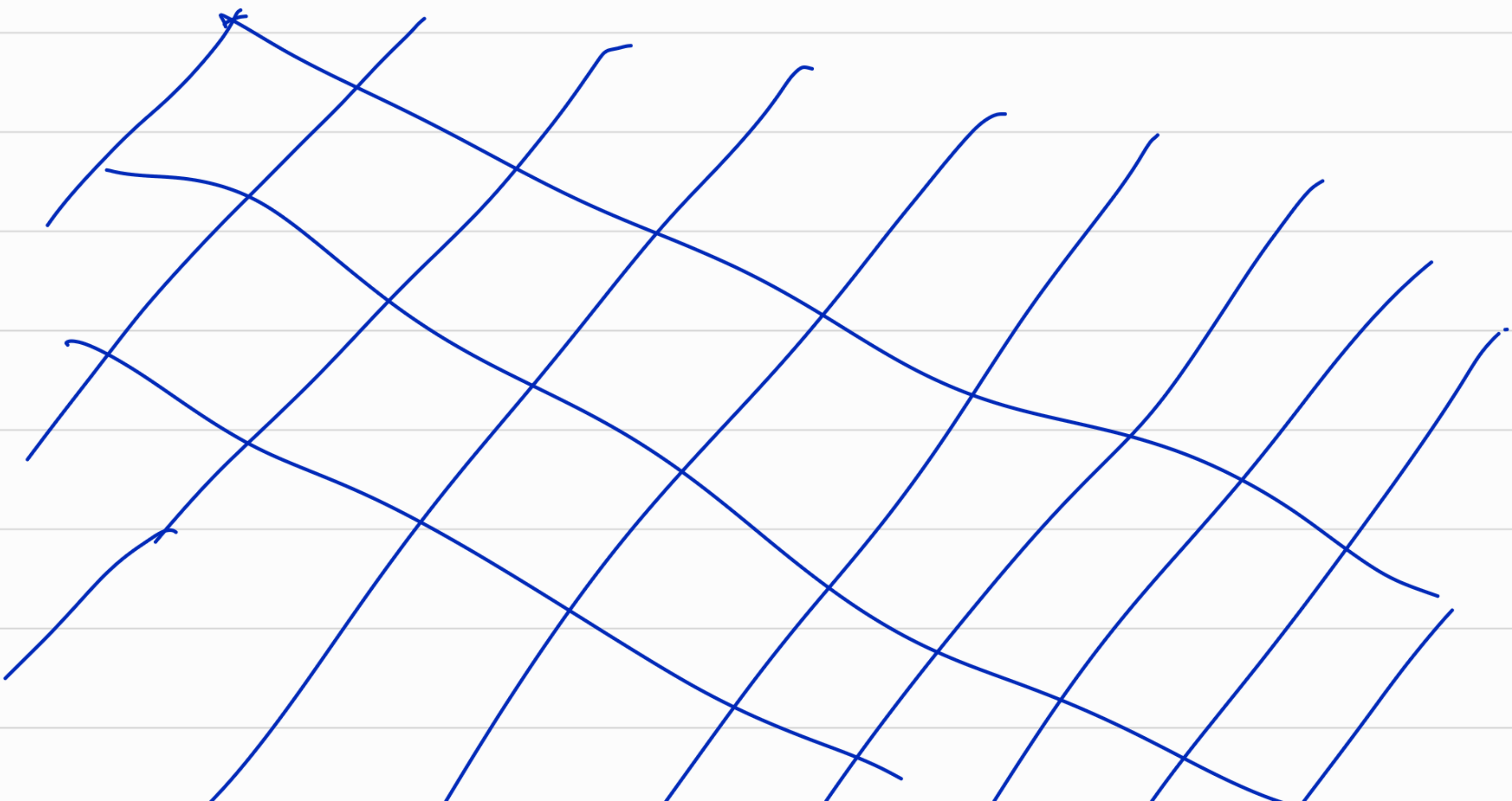
percentage of covered area such that user can establish a call

* what is requrements to establish a call from coverage perspectiva?

1- $P_r \geq P_{min}$ 2- $\frac{C}{I} > \frac{C}{I}\Big|_{min}$

Quality

$$\frac{C}{I} = \frac{P_r(\text{home})}{\sum P_r(\text{interferences})}$$



also called

field survey (Drive Test) → at Runtime

we call enhance the results of drive test & field

survey using **Software** (Atoll)

→ geographical information

software → GIS → hights → المباني العالية (ناطحات السحاب)
  → cluter
  → mapps (road, rever, water surface trees)

→ mathmetical model Pr(?)

inputs

→ traffic mapps → users density on mapp.

→ technical info {antenna, freq, ch., tower hights, cell config.}

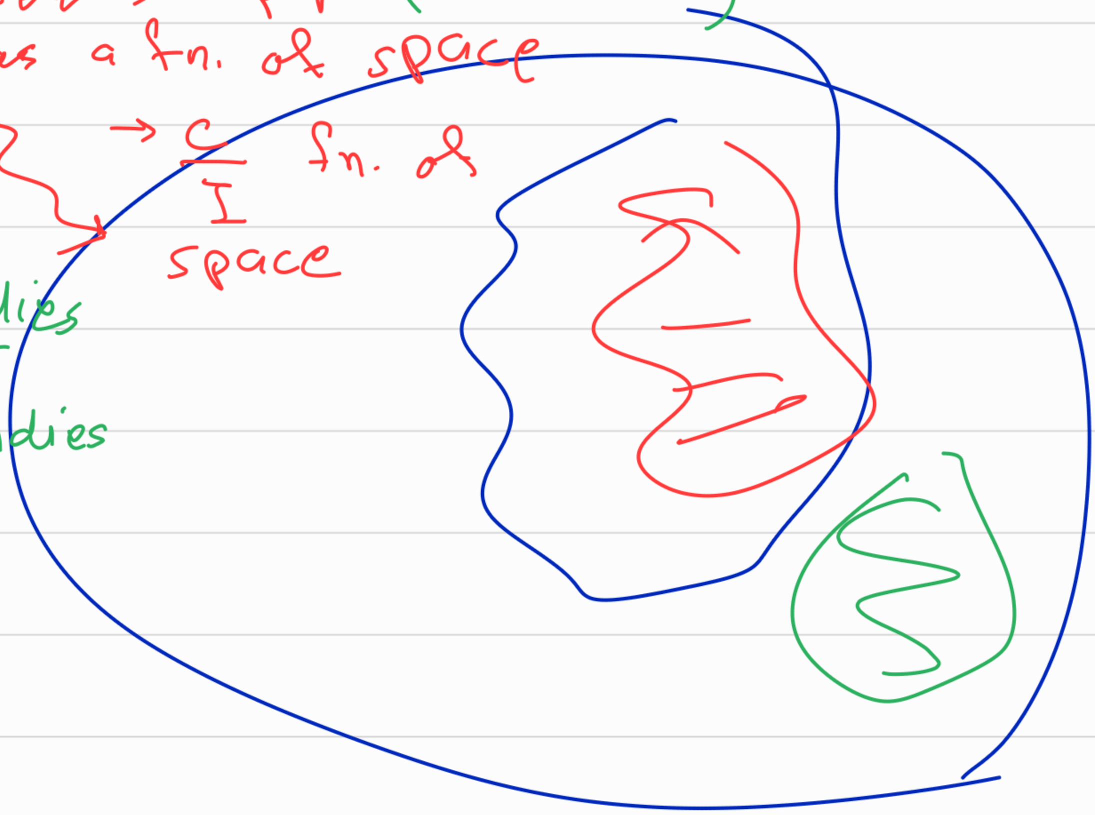
⇓

coverage mapps

output

represents Pr (software) as a fn. of space

→ $\frac{C}{I}$ fn. of space



- traffic studies users amount
- coverage studies area amount

---

different cell sizes:

different size of cells

more dense of users

we call it capacity cells "more users"

D/R (interferer is increase since D_1 is designed to for smaller D/R for D/R)₂

Less designed dense of users

we call it coverage cells "more Area coverage"

$\frac{C}{I}\Big|_{\text{small cells}} > \frac{C}{I}\Big|_{\text{Large cells}}$

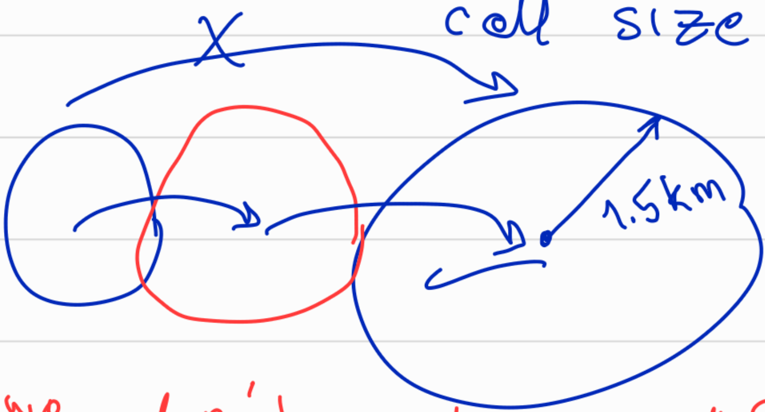
why?, the green color is the answer

sol.

1- reduce small cell's P_t

2- gradual increase of cell size

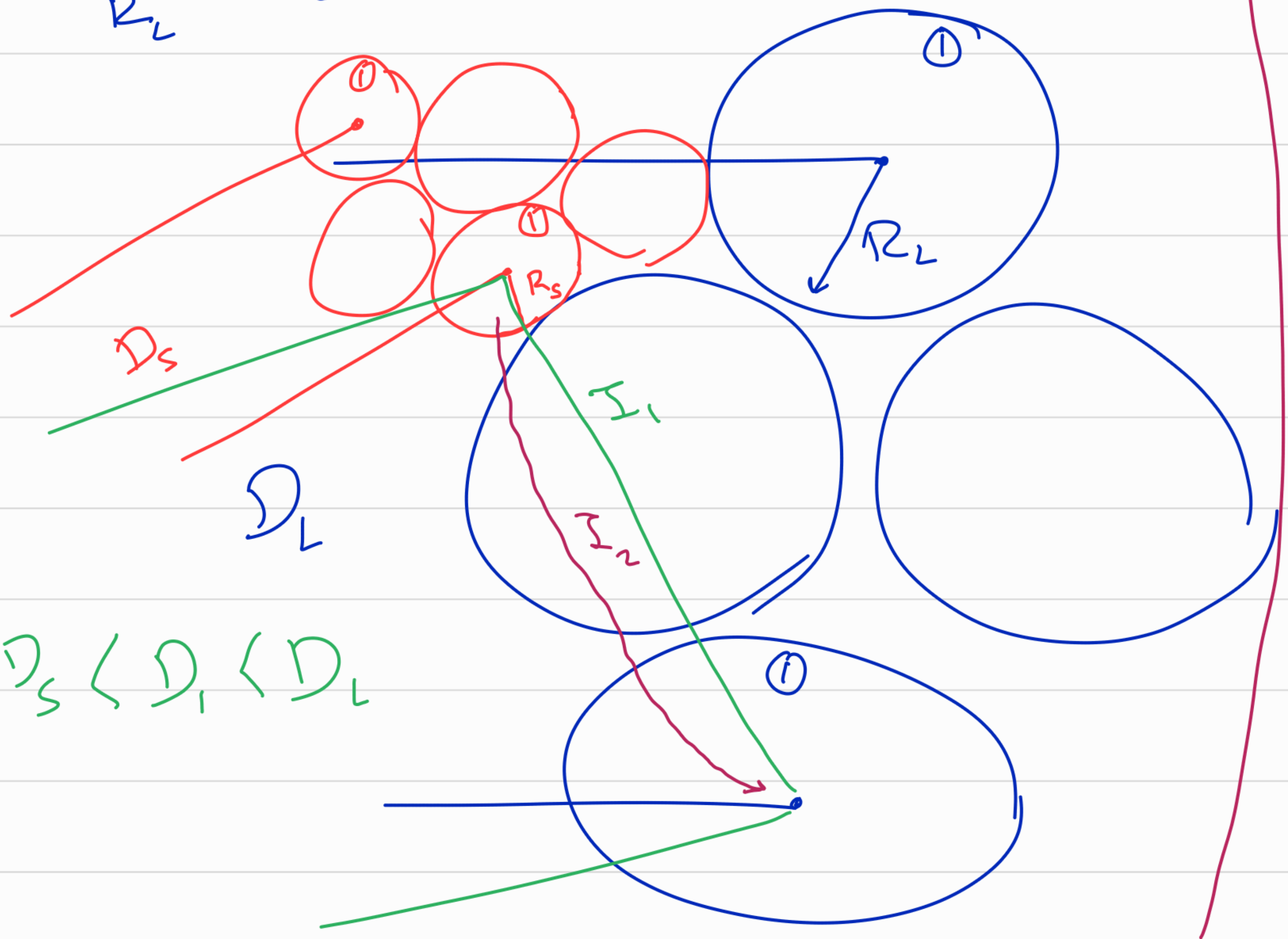
&



we don't make small & large adjecent.

small → meduim → Large
500m 800m 1.5km

$\frac{D_L}{R_L} = q_L = 3$ in 3x3



$D_s < D_1 < D_L$

$I_1 \propto D_1^{-\gamma}$

$C_1 \propto R_s^{-\gamma}$

$$\frac{C_1}{I_1}\Big|_s = \left(\frac{D_1}{R_s}\right)^{\gamma}$$

$$\Rightarrow \frac{D_1}{R_s} > \frac{D_s}{R_s}$$

$I_{Large/small} < I_{small/small}$

$$\frac{C_1}{I_1}\Big|_L = \left(\frac{D_1}{R_L}\right)^{\gamma} < \frac{D_L}{R_L}$$

$$\frac{C}{I}\Big|_s > \frac{C}{I}\Big|_L$$

$\Rightarrow$ so we put meduim cell in between

design criteria is I build a sys. in software → measure Pr at small, meduim, and Large cells $P_r \stackrel{?}{>} P_{r(min)}$ at any point, yes → Good design

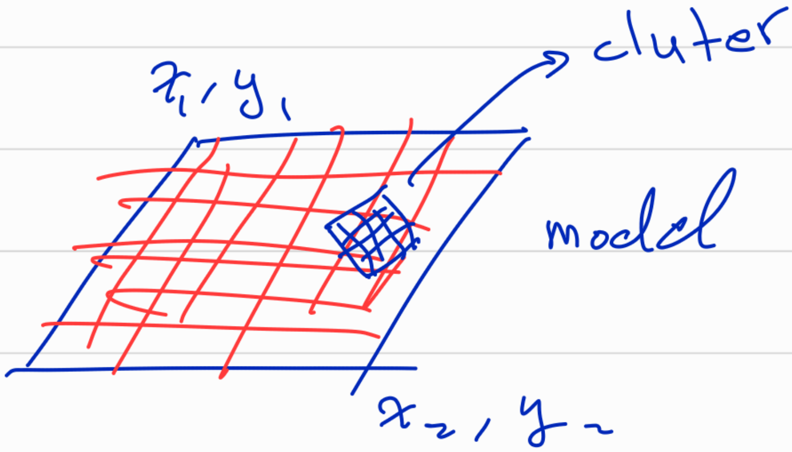
but if $P_r < P_{r(min)}$? I simulated the sys by software, still we didn't build the sys.

GIS: → Database 2 is divided into

Layers

roads ———
trees ———
hights ———
water ———
⋮
coordinate system ———
↘
خطوط الطول والعرض

this is a layer of GIS



we benfit of this: space

calculate $P_r(x, y, z, f, \delta, P_t, G_t, G_r, T$, weather, hights($T_x$, R_x), cluter, ...)

Scenario 1: Free space Model

Guided mode of transmission in space

Tx •———————• Rx

$$G_r = \frac{A_{eff}}{\lambda^2} 4\pi \quad , \quad A_{eff} = \frac{P_r}{P_D}$$

$$P_D = \frac{P_t}{4\pi d^2} = \frac{\lambda^2 G_r}{4\pi}$$

$$P_r = \frac{P_t \cdot \lambda^2 G_r}{(4\pi d)^2} = \frac{P_t \cdot G_r}{\left(4\pi \frac{d}{\lambda}\right)^2}$$

$$\boxed{P_r = \frac{P_t G_t G_r}{\left(4\pi \frac{d}{\lambda}\right)^2}}$$

Free space propogation Model

"comm. sys. course"