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Research Article

DESIGNING THE GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS "GSM-900" CELLULAR NETWORK UP TO THE NOMINAL CELL PLAN IN TRIPOLI, LIBYA

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ABSTRACT

The construction and design of cellular networks are complex processes. They involve the selection of the necessary components and the allocation of support infrastructure. In this study, we introduce an integer programming model that can help network designers maximize their net revenue. The model takes into consideration various factors such as the cost of running a business, the bandwidth available, and the customer area's revenue potential. It also takes into account the sizes and locations of each cell. This research provides a variety of solutions for designing and building cellular networks. This study takes into account the various factors that affect the design and construction of cellular networks. It also takes into account the channel sizes and locations of each cell. It is specific research and given the spectrum (20 MHz), channel bandwidth (200 kHz), and C/I = The minimum operating C/I of 15 dB, a spectrum 20MHz and full-duplex channel bandwidth is 200KHz. The various components of a network's start-up point, such as the network type, multiple access protocols, and control principles, are based on the frequency band for reuse and the table-building process. The cell planning process is based on the code division and frequency division of the GSM frequencies. In code division cases, the users and base stations of the same network are separated by codes.

Keywords: Cellular Networks, Complex Processes, Bandwidth, Cell Planning, GSM.

INTRODUCTION

The development of the cellular concept was largely due to the need to address the issue of user capacity and spectral congestion. It allowed for the use of a lot of spectrums without requiring major technical changes. Instead of a single high-power transmitter, a series of low-power ones are used to cover a specific area within the service area of the cellular concept [1][2]. A base station's position is assigned various sets of channels, which then result in a small number of stations being able to access all of them. By separating the channels, the interference between the base stations and the cellular users is lessened. In this research, we provided the solution for the cellular GSM network in Tripoli city. There will include all stages of GSM mobile network design, but up to the “nominal cell plan”, because after that, there should start work for territory surveys, radio propagation/coverage simulation/calculation, final cell plan (final design) implementation, and so on. The listed, what should go after “nominal cell plan”, does not include in our research, it is the other level in design. Tripoli city has an area of 1507 square kilometers with a population of 3 million. The network should have at least an operating C/I of 15 dB, spectrum 20MHz, and full-duplex channel bandwidth 200KHz. The network will base on GSM, and stations (St,S) will run in the 900 MHz diapason, which will be parcelled out into 2 scopes of 20 MHz (each canal 200 kHz), for downstream to the mobile St (BS to MS) make use of 890 to 910 MHz, for upstream to base St (MS to BS) apply 935 MHz - 955 MHz First, we will define the network boundaries and area map, then the work will go through the below steps:

- For the omnidirectional case will build our clusters by determining the spectrum length and bandwidth for each channel, will write about co-channel interference and co-channel tiers in a hexagonal cellular system, will calculate cluster size, will build clusters topology, and determine/find the positions of co-channel cells. Then will apply it to the directional radio propagation case.
- Build a frequencies table, and calculate cell size in the sites, capacity, and BTS count.
- Carry out financial calculations.
- Draw a nominal cell plan

Before starting we need to draw the zone’s border where we should be deployed our network as shown in (Figure 1) below.

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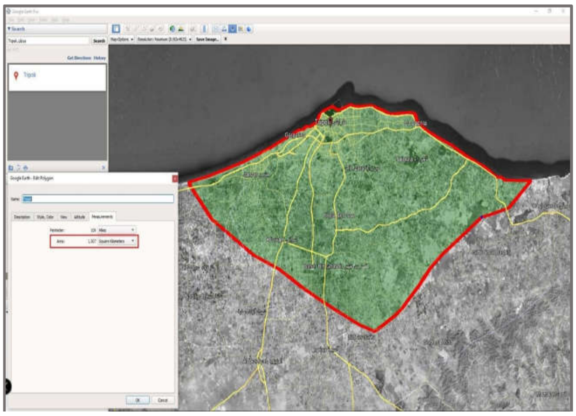


Figure.1 Tripoli, Network's Zone Border

We can take into account – The GSM 900 cellular network is the best and relatively low-cost basement for starting to deploy the cellular network, it provides necessary services, and so on. And if, in the future, will need to provide more speed mobile data for, for example, for Internet, this infrastructure will allow relatively easy deployment of the LTE/4G/5G network." One of the costliest components of constructing a cellular network is frequency planning. The cost of deploying and maintaining the network will go down if a group of base stations can be put up with the least amount of preparation and servicing. Planning and optimization are carried out to guarantee that the precious frequency is used as efficiently as possible. Additionally, this is done to guarantee low to no co-channelling interference and excellent efficiency in cellular radio networks. The goal of this research is to develop an automated method for scheduling and maximizing frequency in the cellular network and building the nominal cell plan for the Global System for Mobile Communications "GSM-900" cellular network in Tripoli, Libya. The method substitutes the time-consuming, laborious, and wasteful manual method. Radiofrequency (RF) engineers' work is made easier and less expensive with the automatic method. The automatic method streamlines tasks for radio frequency (RF) engineers and lowers operating costs. The automatic method makes certain that the cellular network is widely implemented in a way that the requirements of maximum quality, quantity, and high coverage are met. One of the goals of thestudy is to develop an automatic planning and optimization technique that reduces intra-system interference levels to acceptable ranges while maintaining the key performance indicators (KPIs) set for any suitable cellular network [11].The GSM cellular network is the best and relatively low-cost basement for starting to deploy a cellular network, it provides necessary low-cost calling services for customers, and so on. And if, in the future, will need to provide more than GSM mobile data speed, this existing infrastructure will allow relatively easy deploy the LTE/4G/5G/6G network. It is better for Tripoli to start to deploy the GSM network, provide relatively low-cost services, and then, as and when required, start to realize the, for example, the 5G/6G (LTE) network.

CLUSTERS

The cluster consists of sites and cells, i.e., with different working frequencies (in the same frequency range) all sites/cells are grouped in a cluster. First, the necessary calculations for building our cluster will be based on omnidirectional radio propagation. In this case, the "site" and "cell" is the same area/zone. The next stage is applying directional radio propagation conception. It is important for having better C/I and decreasing interference in co-channel cells, reducing the noise level, increasing capacity, and enhancing frequency reuse. Here the cluster will build from "sites" where each "site" consists of a few "cells".

CHANNEL BANDWIDTH AND SPECTRUM LENGTH, FREQUENCY RANGE

The GSM-900 stations are working in the 900 MHz frequency range, which is parcelling out into 2 scopes of 20 MHz (for each channel provided 200 kHz):

- For downstream to the mobile St (BS to MS) using from 890 to 910 MHz
- For upstream to base St (MS to BS) applying 935 MHz - 955 MHz

In GSM for cluster planning, duplex gear, and multiple accesses using the Frequency Division (FD) and Time Division (TD)[1]. Figure 2 and Figure 3) show the duplex distance for the 900 MHz band is 45 MHz [2].

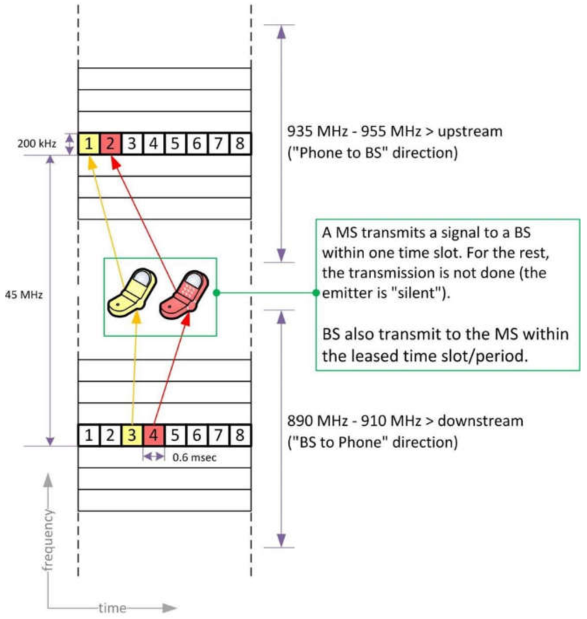


Figure.2 Frequency Division (FD) And Time Division (TD) In Gsm

Within each frequency channel, the data is transmitted across 8-time slots, i.e., each carrier can have 8 connections (Using TD). Eight-time slots are combined in a frame, and 26 frames in a repeater cycle.

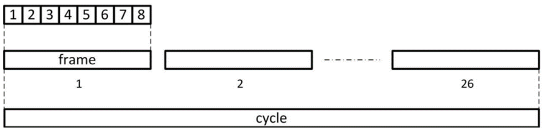


Figure. 3 Time Division (Td) In Gsm

CO-CHANNEL INTERFERENCE. HEXAGONAL CELLULAR SYSTEM AND CO-CHANNEL

In the design and building process of cellular systems, there is except radio coverage exists as no less important goal. It is to provide needful capacity. To increase the capacity of the system, the first step that should be done is frequency reuse. But for each BS there are interferences from stations with the same channel (co-channel interference) and from adjacent frequency channels too. The recommended co-channel interference rate (C/I) and adjacent frequencies interference rate (C/A) [3] are:

- C/I ≥ 9 dB; + additional 3 dB (allowance in engineering) C/I ≥ 12 dB
- C/A ≥ -9 dB; + additional 3 dB C/A ≥ -6 dB

In our research the minimum operating C/I equals 15 dB (in the 1 tier), i.e., must have a C/I ≥ 15 dB value.

For a clear understanding, what is the C/I (carrier to interference rate) in Figure 4 provide the visualization, where:

D – Distance between co-channel's sites/cells
R – Radius of observed (main) site/cell

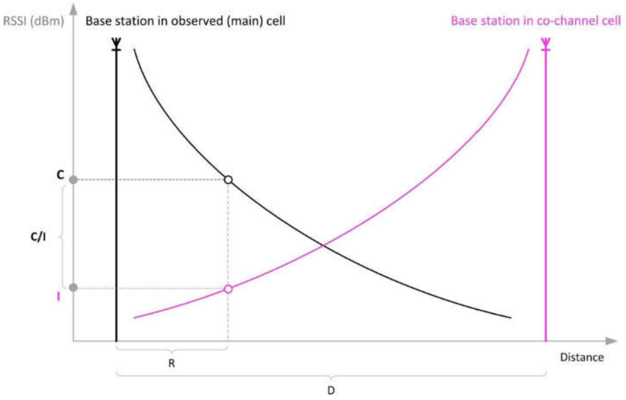


Figure.4 C/I (Carrier-To-Interference Rate) Visualization

To reduce interference, the neighborhood sites'(cells') working channels are not the same. Sites/cells with different frequencies (with different working channels) are grouped in a cluster. In hexagonal architectures, each "n" tier contains "6 x n" co-channel sites/cells [4]. I.e., on the first-tier as the source of interference are six (6 x 1 =6) co-channel sites/cells, on the second-tier – 12, and so on as can be seen in (Figure 5).

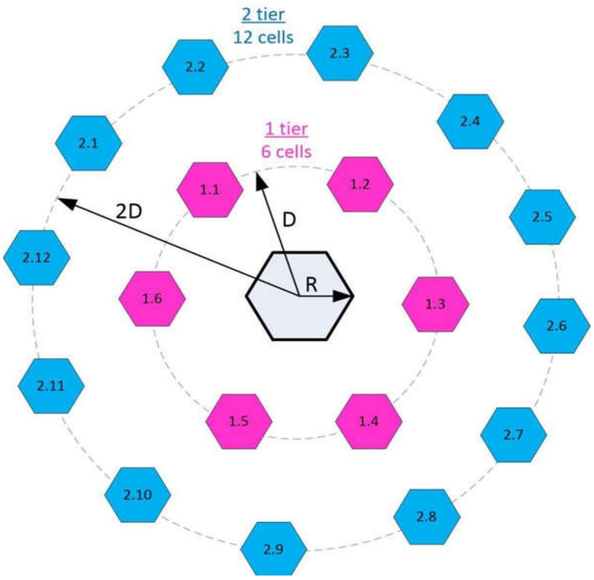


Figure. 5 Co-Channel Tiers In Hexagonal Cellular System

Interference analysis is provided in "2.2 co-channel interference. hexagonal cellular system and co-channel tiers". it is provided because in the task wrote – "minimum operating c/i of 15db", so, c/i is a "carrier to interference rate", and must provide this information. also, c/i used in the, for example, for cluster size calculation (2.3 cluster size calculation). By decreasing the transmission power, interference may be avoided. Co-channel interference can be decreased in a cellular structure by substituting only channels. One directional antenna is surrounded by several directional projections at the base station, each emitting within a defined range and industry [12].

CLUSTER SIZE CALCULATION

Wherever It may seem the best way to decrease the interference is to increase the transmitter's power. More power may be increasing the C/I for this site/cell, but for the co-channel site/cell doing the opposite effect. The cluster size is based on C/I necessary rate and depends on the D and R values as illustrated in (Figure 4, and Figure 5) [5].

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

Equation 1 | Co-Channel Reuse Ratio

N – It is a count of sites/cells in the cluster, in other words, it is the cluster size. After calculating the cluster size, the following formula shows the cluster size value[4].

$$\frac{C}{I} = \frac{\left(\frac{D}{R}\right)^{\alpha}}{6}$$

Equation 2 | C/I On R Distance

In our research, the minimum C/I = 15 dB = 31.6228 [6]. Based on the value of α which is known as a path-loss exponent, it can take the below values as shown in Table 1 [7]:

Table 1. Path-Loss Exponent Value

Environment	Path-Loss exponent, α
Free space	2
Urban area cellular	2.7 to 3.5
Shadowed urban cellular	3 to 5
In building LoS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

So, in our case, α = 2.7 to 3.5, we choose the "3.5" value.

$$\frac{C}{I} = \frac{\left(\frac{D}{R}\right)^{3.5}}{6} \quad \text{and} \quad \frac{D}{R} = \left(\frac{6 \times C}{I}\right)^{1/3.5}$$

As selected above $\frac{D}{R} = \sqrt{3 \times N}$

By using the above formulas and after calculations, the findings were as the following:

$$N = \frac{1}{3} \times \left(\frac{6 \times C}{I}\right)^{2/3.5}$$

$$N = \frac{1}{3} \times (6 \times 31.6228)^{0.57} = \frac{1}{3} \times 189.7368^{0.57} = \frac{1}{3} \times 19.886$$

$N = 6.629$

Equation 3 | Cluster Size Calculation - Part2

N can be 3, 7, or 12 [8].

Our cluster should be having a minimum of 7 sites/cells. Our choice is N=7. N=7 cluster example in Figure 6.

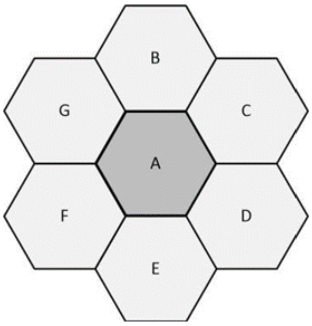


Figure. 6 Cluster Cell

A, B, C, …, G are sites/cells in the same cluster which use different frequencies in the same range, for example for downstream, in the 890 – 910 MHz So, we can use the whole 20MHz in one cluster and reuse the same frequency many times in other clusters as can be seen in (Figure 7).

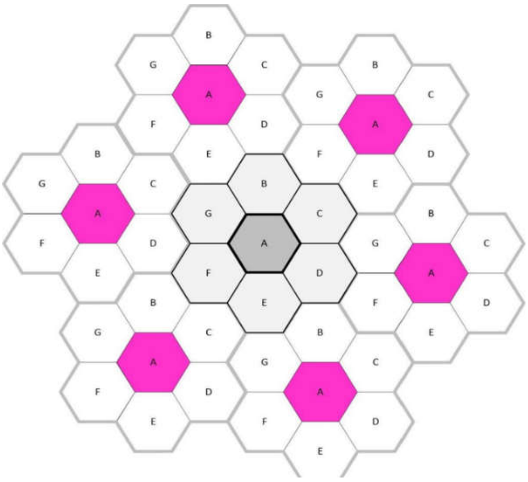


Figure. 7 Example Of Observed Cluster And His Nearest Six Clusters

CLUSTERS TOPOLOGY (THE CO-CHANNEL CELLS POSITIONS)

The network should provide the required capacity and radio coverage. The cluster will have 7 sites/cells. With additional clusters, we will increase our cellular network if one cluster is not enough to cover the required zone. Our cell and co-channel 6 cells disposition (on tier 1) preview as shown in Figure 8.

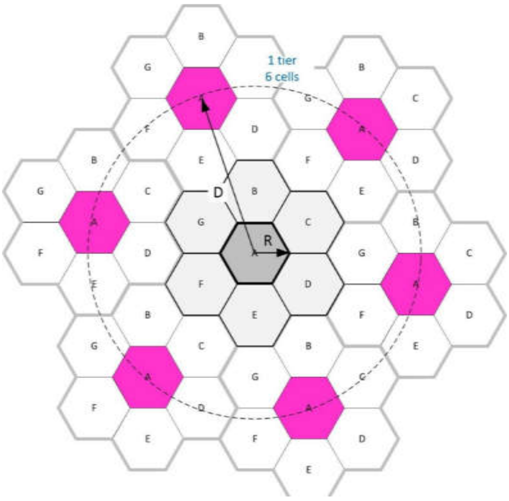


Figure. 8 Our Cell And Co-Channel 6 Cells Disposition (Tier 1)

When we design and build the cellular network, we must determine the positions of the co-channel cells in the "surround" clusters (tier1). Where are they should be? Are they in the center of the cluster, or near the border of clusters? To find necessary positions we should from our observed site/cell count "i" cells in any direction, then rotate 60° counterclockwise and continue moving forward at "j" cells – as shown in Figure 9.

"i" and "j" values depend on cluster size ("N") [4].

$D = \sqrt{(i^2 + i \times j + j^2)} \times (R \times \sqrt{3})$

Equation 4 | The Distance Between Co-Channel Sites/Cells

We know that $\frac{D}{R} = \sqrt{3 \times N}$

So, the "N" value can preview as in Equation 5 (Tipper, n.d., p. 7) [8].
$N = i^2 + i \times j + j^2$

Equation 4 | "N" Value Via "I" And "J"

In our case N=7, so, we have N=7 (i=2, j=1).

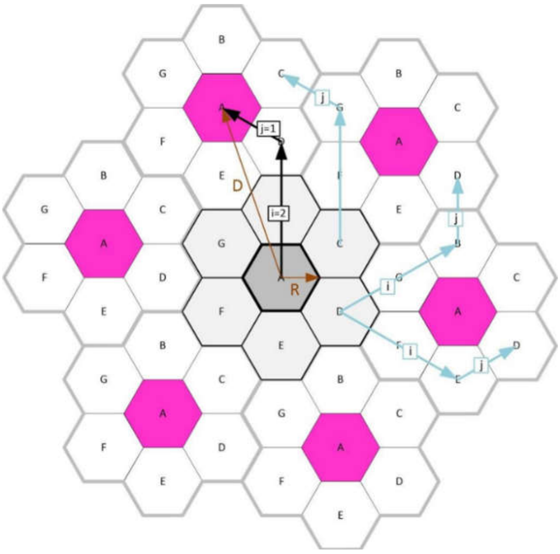


Figure. 9 Co-Channel Cells Position Calculation

1. Sectors In Radio Propagation (Changing To Directional Radio Propagation)

Base Station Systems (BSS) provides access to services for mobile customers. Each BSS consists of Base Station Controller (BSC) and Base Transceiver Station (BTS).BTS - includes radio devices (transceiver, receiver, etc.) and antennas. BSC - manages the BTS and the whole radio network [2]. Co-channel cells' quantity and positions, when each BTS used an omnidirectional antenna and via one antenna to cover 3600, were previewed before. The next step is splitting the 3600 directions into 3 directions (1200 sectoring). What will we have?

- Better C/I, reducing interfering co-channel cells quantity (Tipper, n.d., p. 17) [8] as shown in (Figure 10);
- Directional antennas reducing noise level;
- It is increasing capacity, and enhancing frequency reuse.

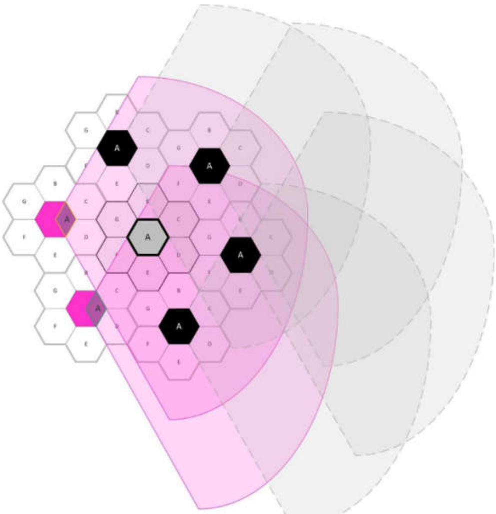


Figure. 10 Sectoring –Interfering Co-Channel Cells Quantity To 2

THE CLUSTERS TOPOLOGY IN SECTORING RADIO PROPAGATION

In sectoring, radio propagation applied another method for building the clusters. We will divide the sites into three zones where each zone is the cell. In omnidirectional radio propagation, the “site” and “cell” is the same area/zone. In directional radio propagation, the cluster will build from “sites” where each "site" consists of three “cells” as illustrated in (Figure 11).

The BTS was placed on the junction point of three cells. Each cell provides 1200 covering by the directional antenna and each cell will use its frequencies. For example, in the “A” site they are A1, A2, and A3 (Figure 11).

The cluster we will present with the pattern’s notation X/Y.

X – sites count in the cluster.
Y – cells count in the cluster.

The cluster size has already been calculated. Our cluster consists of 7 sites, i.e., have a 7/21 pattern. It means that the cluster will have 7 sites which will cover 21 zones [2].

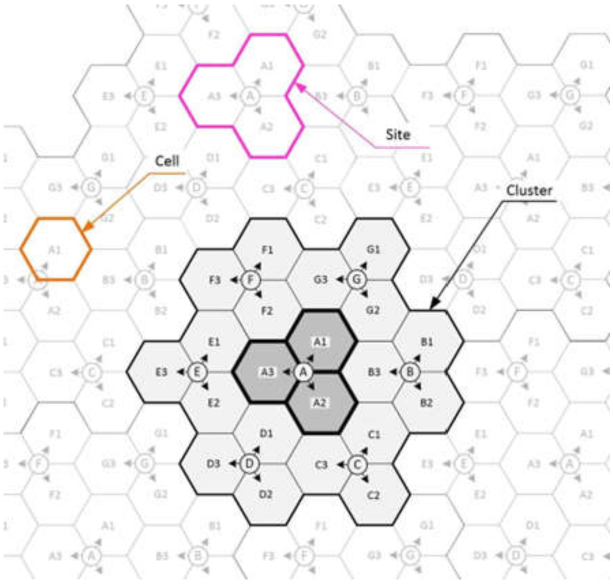


Figure. 11 Clusters In Sectoring Radio Propagation

FREQUENCY RANGE, COUNT F CHANNELS

In Part, the BTS to MS uses frequencies from 890 MHz to 910 MHz, for MS to BTS from 935 MHz to 955 MHz and for each direction, we have 20 MHz spectrum, for each channel 200 kHz. So, we will have 20 MHz/200 kHz = 100 channels (100 carriers) for duplex links in each cluster.

As we draw in Figure 2 above, each carrier provided multiple accesses and 8 connection channels per carrier. So, our capacity for each cluster is 8 x 100 = 800 connections, i.e., 800 calls possibility in a zone covered by one cluster.

The cluster will have a 7/21 pattern, 100 carriers/800 connections per cluster. Take into account that the subscribers’ load is uniformly distributed in the cluster, so, in the cluster, we will have for 16 cells the 5 carriers/40 connections per cell, for the remaining 5 cells the 4 carriers/32 connections per cell.

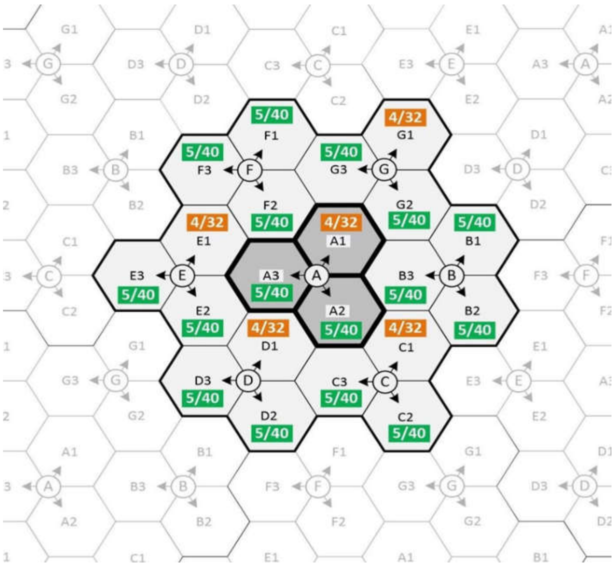


Figure. 12 Carriers/Channels In The Cells

In the real network, depending on some situations, for example, depending on subscribers' loads, one cell maybe will need more channels, another one has fewer channels, etc. So, when will need it, we can “withdraw” channels from one cell to another one. Table 2 below shows the frequencies channels values.

Table 2. Frequencies. Channels List

Cell	carriers/ connections	BS-MS/MS-BS MHz
A1	4/32	890/935
		894.2/939.2
		898.4/943.4
		902.6/947.6
A2	5/40	891.4/936.4
		895.6/940.6
		899.8/944.8
		904/949
		908.2/953.2
A3	5/40	892.8/937.8
		897/942
		901.2/946.2
		905.4/950.4
		909.6/954.6
B1	5/40	890.2/935.2
		894.4/939.4
		898.6/943.6
		902.8/947.8
		907/952
B2	5/40	891.6/936.6
		895.8/940.8
		900/945
		904.2/949.2
		908.4/953.4
B3	5/40	893/938
		897.2/942.2
		901.4/946.4
		905.6/950.6
		909.8/954.8
C1	4/32	890.4/935.4
		894.6/939.6
		898.8/943.8
		903/948
C2	5/40	891.8/936.8
		896/941
		900.2/945.2
		904.4/949.4
		908.6/953.6
C3	5/40	893.2/938.2
		897.4/942.4
		901.6/946.6
		905.8/950.8
		906.8/951.8
D1	4/32	890.6/935.6
		894.8/939.8
		899/944
		903.2/948.2
D2	5/40	892/937
		896.2/941.2
		900.4/945.4
		904.6/949.6
		908.8/953.8
D3	5/40	893.4/938.4
		897.6/942.6
		901.8/946.8
		906/951
		907.2/952.2

Channel Carrier	BS-MS/MS-BS MHz
Ch 1	890/935
Ch 2	890.2/935.2
Ch 3	890.4/935.4
Ch 4	890.6/935.6
Ch 5	890.8/935.8
Ch 6	891/936
Ch 7	891.2/936.2
Ch 8	891.4/936.4
Ch 9	891.6/936.6
Ch 10	891.8/936.8
Ch 11	892/937
Ch 12	892.2/937.2
Ch 13	892.4/937.4
Ch 14	892.6/937.6
Ch 15	892.8/937.8
Ch 16	893/938
Ch 17	893.2/938.2
Ch 18	893.4/938.4
Ch 19	893.6/938.6
Ch 20	893.8/938.8
Ch 21	894/939
Ch 22	894.2/939.2
Ch 23	894.4/939.4
Ch 24	894.6/939.6
Ch 25	894.8/939.8
Ch 26	896/940
Ch 27	895.2/940.2
Ch 28	895.4/940.4
Ch 29	895.6/940.6
Ch 30	895.8/940.8
Ch 31	896/941
Ch 32	896.2/941.2
Ch 33	896.4/941.4
Ch 34	896.6/941.6
Ch 35	896.8/941.8
Ch 36	897/942
Ch 37	897.2/942.2
Ch 38	897.4/942.4
Ch 39	897.6/942.6
Ch 40	897.8/942.8
Ch 41	898/943
Ch 42	898.2/943.2
Ch 43	898.4/943.4
Ch 44	898.6/943.6
Ch 45	898.8/943.8
Ch 46	899/944
Ch 47	899.2/944.2
Ch 48	899.4/944.4
Ch 49	899.6/944.6
Ch 50	899.8/944.8

Channel Carrier	BS-MS/MS-BS MHz
Ch 51	900/945
Ch 52	900.2/945.2
Ch 53	900.4/945.4
Ch 54	900.6/945.6
Ch 55	900.8/945.8
Ch 56	901/946
Ch 57	901.2/946.2
Ch 58	901.4/946.4
Ch 59	901.6/946.6
Ch 60	901.8/946.8
Ch 61	902/947
Ch 62	902.2/947.2
Ch 63	902.4/947.4
Ch 64	902.6/947.6
Ch 65	902.8/947.8
Ch 66	903/948
Ch 67	903.2/948.2
Ch 68	903.4/948.4
Ch 69	903.6/948.6
Ch 70	903.8/948.8
Ch 71	904/949
Ch 72	904.2/949.2
Ch 73	904.4/949.4
Ch 74	904.6/949.6
Ch 75	904.8/949.8
Ch 76	905/950
Ch 77	905.2/950.2
Ch 78	905.4/950.4
Ch 79	905.6/950.6
Ch 80	905.8/950.8
Ch 81	906/951
Ch 82	906.2/951.2
Ch 83	906.4/951.4
Ch 84	906.6/951.6
Ch 85	906.8/951.8
Ch 86	907/952
Ch 87	907.2/952.2
Ch 88	907.4/952.4
Ch 89	907.6/952.6
Ch 90	907.8/952.8
Ch 91	908/953
Ch 92	908.2/953.2
Ch 93	908.4/953.4
Ch 94	908.6/953.6
Ch 95	908.8/953.8
Ch 96	909/954
Ch 97	909.2/954.2
Ch 98	909.4/954.4
Ch 99	909.6/954.6
Ch 100	909.8/954.8

Cell	carriers/ connections	BS-MS/MS-BS MHz
E1	4/32	890.8/935.8
		895/940
		899.2/944.2
		903.4/948.4
E2	5/40	892.2/937.2
		896.4/941.4
		900.6/945.6
		904.8/949.8
		909/954
E3	5/40	893.6/938.6
		897.8/942.8
		902/947
		906.2/951.2
		907.4/952.4
F1	5/40	891/936
		895.2/940.2
		899.4/944.4
		903.6/948.6
		907.8/952.8
F2	5/40	892.4/937.4
		896.6/941.6
		900.8/945.8
		905/950
		909.2/954.2
F3	5/40	893.8/938.8
		898/943
		902.2/947.2
		906.4/951.4
		907.6/952.6
G1	4/32	891.2/936.2
		895.4/940.4
		899.6/944.6
		903.8/948.8
G2	5/40	892.6/937.6
		896.8/941.8
		901/946
		905.2/950.2
		909.4/954.4
G3	5/40	894/939
		898.2/943.2
		902.4/947.4
		906.6/951.6
		908/953

CELL SIZE

The traffic intensity also can vary depending on the area. It is clear, that in this case, the cell can have different sizes. In high traffic cases, in a region are placed the small cells. When traffic is low, large cells are placed. Figure 13 provided the selected example of this situation by Ericsson (Ericsson - Student Text En/Lzt 123 3314 R3a, 1998) [2].

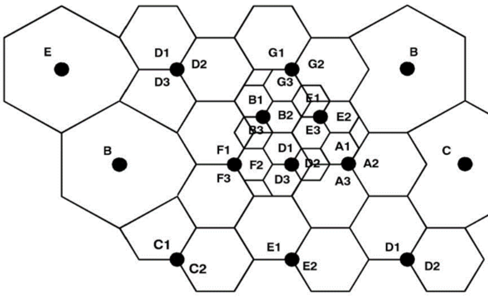


Figure. 13 Cells Of Different Sizes

In addition to radio coverage calculation, to determine the radius of the cell (R), the following data are analysed:

A. Roads and highways' direction and congestion:

- The subscriber load's density;
- Capacity requirements.

B. Cells by size qualified as[1]:

- "MACRO" cell (up to 35 km);
- "MICRO" cell (up to 2 km);
- "PICO" cell (up to 100 m).

The small cells provide more capacity, but cars and any other object moving at high speed will frequently jump from one cell's BTS to another one BTS. When clusters build big cells, the other problem will become, that the total capacity will be lower.Thus, the topology of the BTS should be adapted to the value, density, and territorial distribution of the subscriber loads.

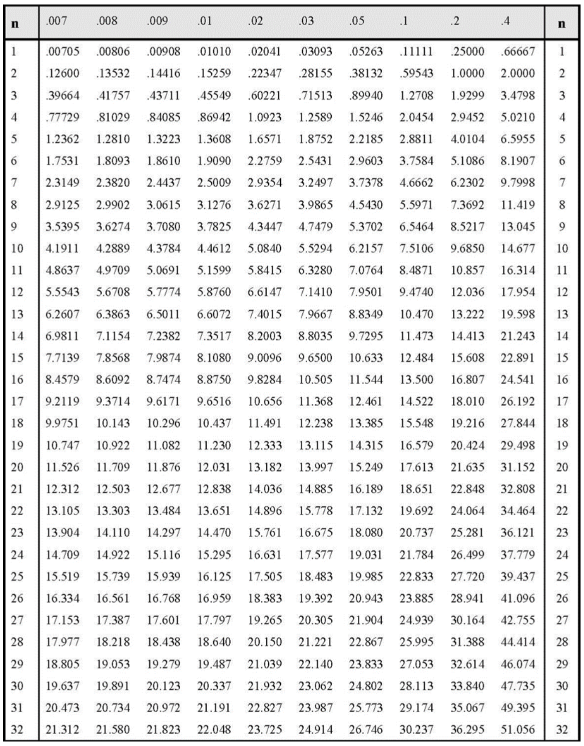
ZONE OF TRANSITION

If the clusters have different sizes of cells, it provides problems in channel planning because the distance D is will be different for cells with different sizes. The small cells are interfering with the large cell. So, there must be a buffer zone where the small and big cells must not use the same frequencies. If we will use all frequencies in our cluster, we will not have a reserve for buffer zones, and will not have a reserve for additional BTS for future installation also. Additional BTS will need if will need to increase capacity in the existing cluster. So, for cells we will not use all available channels/carriers, we can use some channels as per (Table 2) and not use and reserve those for the future. For example, we can from 5 carriers/40 connections (5/40) as illustrated above in (Figure 12, Table 2) which does not use some carriers (channels) and reserve those for the future.Otherwise, to increase the capacity, we should do our cells small, which will decrease cluster size and we should be building additional clusters to cover our network's area.

GRADE OF SERVICE (GOS)

Cellular network capacity depends on the count of the available channel and grade of service (GoS). The probability of blocking calls (GoS) is the percentage of failed attempts to set up a connection due to network congestion. To simplify cell capacity calculations, the results of the calculations are usually given in the form of an Erlang B table [2], as explained in (Table 3) below. Rows (n) – number of traffic channel Columns (GoS) – a function of the GoS acceptable value is 2% [2]. As per Table 3 extraction, it is found to be 2% = .02.

Table 3. Erlang B Table



n	.007	.008	.009	.01	.02	.03	.05	.1	.2	.4	n
1	.00705	.00806	.00908	.01010	.02041	.03093	.05263	.11111	.25000	.66667	1
2	.12600	.13532	.14416	.15259	.22347	.28155	.38132	.59543	1.0000	2.0000	2
3	.39664	.41757	.43711	.45549	.60221	.71513	.89940	1.2708	1.9299	3.4798	3
4	.77729	.81029	.84085	.86942	1.0923	1.2589	1.5246	2.0454	2.9452	5.0210	4
5	1.2362	1.2810	1.3223	1.3608	1.6571	1.8752	2.2185	2.8811	4.0104	6.5955	5
6	1.7531	1.8093	1.8610	1.9090	2.2759	2.5431	2.9603	3.7584	5.1086	8.1907	6
7	2.3149	2.3820	2.4437	2.5009	2.9354	3.2497	3.7378	4.6662	6.2302	9.7998	7
8	2.9125	2.9902	3.0615	3.1276	3.6271	3.9865	4.5430	5.5971	7.3692	11.419	8
9	3.5395	3.6274	3.7080	3.7825	4.3447	4.7479	5.3702	6.5464	8.5217	13.045	9
10	4.1911	4.2889	4.3784	4.4612	5.0840	5.5294	6.2157	7.5106	9.6850	14.677	10
11	4.8637	4.9709	5.0691	5.1599	5.8415	6.3280	7.0764	8.4871	10.857	16.314	11
12	5.5543	5.6708	5.7774	5.8760	6.6147	7.1410	7.9501	9.4740	12.036	17.954	12
13	6.2607	6.3863	6.5011	6.6072	7.4015	7.9667	8.8349	10.470	13.222	19.598	13
14	6.9811	7.1154	7.2382	7.3517	8.2003	8.8035	9.7295	11.473	14.413	21.243	14
15	7.7139	7.8568	7.9874	8.1080	9.0096	9.6500	10.633	12.484	15.608	22.891	15
16	8.4579	8.6092	8.7474	8.8750	9.8284	10.505	11.544	13.500	16.807	24.541	16
17	9.2119	9.3714	9.6171	9.6516	10.656	11.368	12.461	14.522	18.010	26.192	17
18	9.9751	10.143	10.296	10.437	11.491	12.238	13.385	15.548	19.216	27.844	18
19	10.747	10.922	11.082	11.230	12.333	13.115	14.315	16.579	20.424	29.498	19
20	11.526	11.709	11.876	12.031	13.182	13.997	15.249	17.613	21.635	31.152	20
21	12.312	12.503	12.677	12.838	14.036	14.885	16.189	18.651	22.848	32.808	21
22	13.105	13.303	13.484	13.651	14.896	15.778	17.132	19.692	24.064	34.464	22
23	13.904	14.110	14.297	14.470	15.761	16.675	18.080	20.737	25.281	36.121	23
24	14.709	14.922	15.116	15.295	16.631	17.577	19.031	21.784	26.499	37.779	24
25	15.519	15.739	15.939	16.125	17.505	18.483	19.985	22.833	27.720	39.437	25
26	16.334	16.561	16.768	16.959	18.383	19.392	20.943	23.885	28.941	41.096	26
27	17.153	17.387	17.601	17.797	19.265	20.305	21.904	24.939	30.164	42.755	27
28	17.977	18.218	18.438	18.640	20.150	21.221	22.867	25.995	31.388	44.414	28
29	18.805	19.053	19.279	19.487	21.039	22.140	23.833	27.053	32.614	46.074	29
30	19.637	19.891	20.123	20.337	21.932	23.062	24.802	28.113	33.840	47.735	30
31	20.473	20.734	20.972	21.191	22.827	23.987	25.773	29.174	35.067	49.395	31
32	21.312	21.580	21.823	22.048	23.725	24.914	26.746	30.237	36.295	51.056	32

SUBSCRIBERS COUNT CALCULATION IN ONE CELL

We can calculate traffic by a subscriber (A_{sub}) [1]. Traffic is measured in Erlangs (E).

n – Count of connections during the 1-hour T – Average talk time during connection (sec) 3600 – 1 hour (3600 sec).

$$A_{sub} = \frac{n \times T}{3600}$$

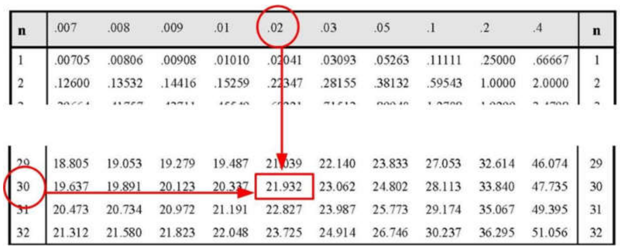
Equation 5 | Subscriber Traffic Calculation

Research showed that Asub typically = 15-20 m [2]. We choose Asub = 20 mE = 0.02 E.

GoS = 2% = 0.02

For our cluster with 7/21 pattern, in case of for cell 4/32 (4carriers/32connections), cell's traffic connection channels = 32 – 2 (control channels) = 30, i.e., n=30

The traffic value for our cell in a cluster with a 7/21 pattern will find in the Erlang B as shown in (Table 3) below.



n	.007	.008	.009	.01	.02	.03	.05	.1	.2	.4	n
1	.00705	.00806	.00908	.01010	.02041	.03093	.05263	.11111	.25000	.66667	1
2	.12600	.13532	.14416	.15259	.22347	.28155	.38132	.59543	1.0000	2.0000	2
29	18.805	19.053	19.279	19.487	21.039	22.140	23.833	27.053	32.614	46.074	29
30	19.637	19.891	20.123	20.337	21.932	23.062	24.802	28.113	33.840	47.735	30
31	20.473	20.734	20.972	21.191	22.827	23.987	25.773	29.174	35.067	49.395	31
32	21.312	21.580	21.823	22.048	23.725	24.914	26.746	30.237	36.295	51.056	32

Figure. 14 With 7/21 Pattern Cluster's Cell Traffic Value

So, A_{cell} = 21.932 E as justified in (Figure 14) above. The subscribers count per cell = $A_{cell} \div A_{sub}$ = 21.932 ÷ 0.02 = 1096 subscribers per cell.

CELL'S RADIUS "R" CALCULATION. BTS COUNT

The final count of BS is determined by two parameters:

- Providing ongoing (continuous) radio coverage.
- Providing the required capacity.

Keeping the requirements for signal strength and quality, we need to provide ongoing radio coverage of a given area. The count of BTS should be enough to service the required number of subscribers and support the required capacity.

Tripoli city:

- Has an area of about 1507 km2
- Number of people – 3 million.

The services' zone border already drew (page 5). It is around 1507 km2 area. About 1 500 000 – 1 700 000 potential mobile users can be available in Tripoli. In the near future, on startup, we can assume that we will have around 300 000 subscribers. We can provide service for 1096 subscribers per cell. So, we will need 300 000 ÷ 1096 = ~273-274 cells to provide service for 300 000 subscribers.

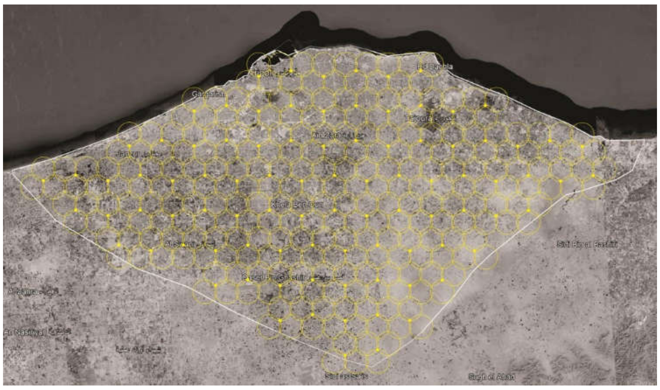
7/21 clusters have 21 cells and 7 BTS with 3 sectors, each BTS provides coverage for 3 cells, and each sector provides coverage for 1 cell. For 300 000 subscribers, we should have 273 ÷ 21 = 13 clusters. In total, for 300 000 subscribers, we should have 13 x 7 (or 273÷3) = 91 BTS. Assuming a uniform network load throughout the service area, also that our network should have 273 cells and taking into account that services an area of about 1507 km2, then each cell will have about 1507 ÷ 273 = ~ 5.6 km2 area.The cell's radius (R) can be calculated as the following:

$$S = \pi \times R^2$$
$$5.6 = 3.14 \times R^2$$
$$R^2 = 5.6 \div 3.14 = \sim 1.79$$
$$R = \sqrt{1.79}$$
$$R = \sim 1.34\ km$$

Equation 6 | Cell's Radius Calculation

NOMINAL CELL PLAN

When drawing up the nominal plan we will assume that the load is evenly distributed throughout the service area. Our cell's R = 1.34 km, we should provide ongoing (continuous) radio coverage, so we will divide the selected area into 273 circles with R = 1.34 km (Figure 15).



Based on **Figure 15** we will draw a nominal cell plan as shown in Table 4 and (Figure 16) below.

Table 4. Nominal Cell Plan Components

Cells	273
BSS (sites)	91
BTS	91
Clusters	13

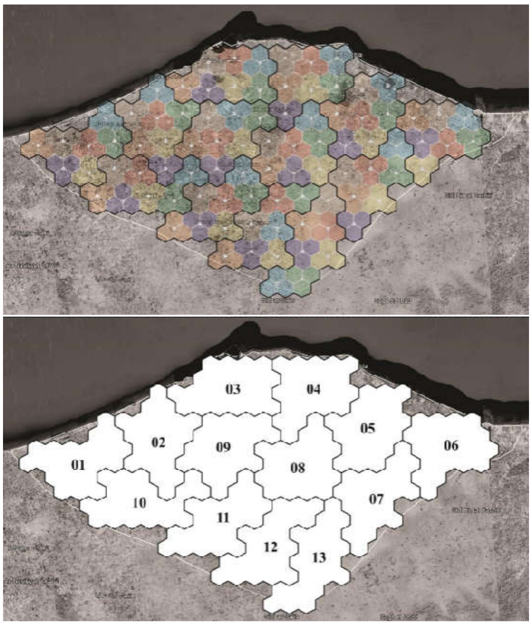


Figure. 16 7/21 Pattern Cluster's Cell Traffic Value

RESULTS AND CONCLUSION

During our work, we based on provided in the research cellular networks base parameters, such as C/I, a spectrum, and full-duplex channel bandwidth values. Our network has an area of 1507 km2, in Tripoli city, Libya. There are about 1500000 – 1700000 potential subscribers can be available, but on start-up, we designed our GSM-900 mobile network for around 300000 subscribers. Then, we planned and calculated additional investment for this network to provide service for additional 60000 subscribers. 60000 subscribers - this is a 20% increase in subscribers over the next 5 years. When designinga start-up network for 300000 subscribers and drawing up the nominal plan, we assumed that the load is evenly distributed throughout the service area.

In a cellular network, when using directional radio propagation, the three cells group in one site and are covered by one BTS with three 1200-distributed sectors, one for each cell. Seven sites were grouped in one cluster that used the whole 20MHz range. So, our cluster was built with a 7/21 pattern, i.e.,7 sites/21 cells.The same frequencies can reuse many times in other clusters. We used FD and TD conceptions, where TD allows through one channel (carrier) has 8 connections. If we do not keep reserve frequencies for network future expansion, then in one cluster we have100carriers/800connections per cluster, where for 16 cells the 5carriers/40 connections per cell (5/40) and for the remaining 5 cells the 4carriers/32 connections per cell (4/32). In 4/32 cases each cell can provide service for up to 1096 subscribers. The network area was divided into 273 cells and each of them had about 1.34 km radius. So,to cover our network area we deployed 13 clusters with 91 BTS in total.The network area's borders are not an ideal figure which can be covered with ideal form factor clusters, so when we deployed our cells and build clusters, as can see in the nominal plan, there are some territories which outside of our clusters' theoretical borders. Will we need to cover those zones too or not, it will be clear during the network working. During the network, working will be clear where will have more traffic loads and where will have fewer traffic loads too. Also, on start-up, we don't know when will have an increase in subscribers by selected 20% (60 000 subscribers), where they increase the traffic loads, i.e., where we will need to deploy additional "powers", additional sectors, or BTS.

So, we must have reserved from available channels (carriers). Our cell count is calculated based on the data that each cell can support up to 1096 clients, i.e., in the 4/32 cells case. To have the reserved channels we may not use all available channels/carriers, i.e., some of them will reserve for the future. For example, we can from 5 carriers/40 connections (5/40) not use some carriers (channels) and reserve those. Or during the network work detect where have fewer loads and withdraw from those cells, the "extra" frequencies (channels).

In the work provided all the necessary information at provide information are discussed:

- about each channel bandwidth and spectrum length, about frequency range.
- about co-channel interference, how the type of cellular system is used (HEXAGONAL), and about c0-channel tiers
- about cluster and cell size
- about clusters topology and cells position
- about why will use directional radio propagation (sectoring radio propagation)
- about Grade of Service (GOS)
- about subscribers count per one cell
- about cell radius, BTS counts, etc…
- provide financing calculations, etc…

I.e., provide all technical details for the design and deployment network up to the "Nominal Plan" stage, because after that there should start work for territory surveys, radio propagation/coverage simulation/calculation, final cell plan (final design) implementation, and so on. The listed, what should go after "nominal cell plan", does not include in this task, it is the other level in design (wrote about it in the introduction and in the results and conclusion). The "Nominal Cell Plan" is provided too.

STARTING INVESTMENT FOR DEPLOYMENT OF OUR CELLULAR NETWORK

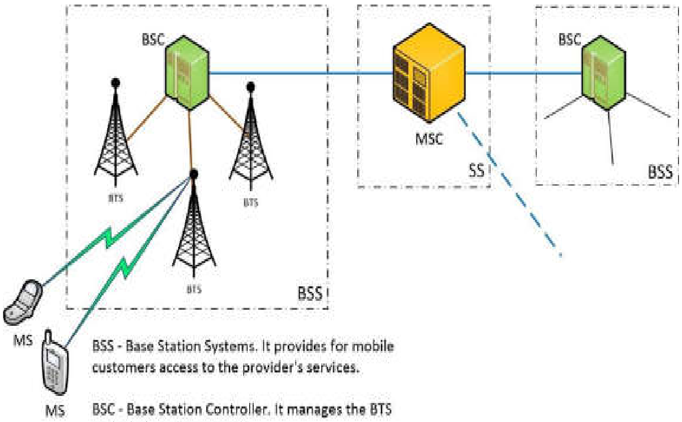


Figure 16. Cellular Network Work

In the research, as can be seen in Figure 16, we already provided a calculation for one BS (BSS = BSC+BTS). BSS = USD 100000K. It includes one BSC and one BTS with 3 sector TX (antenna + transmitter) (each sector cost = USD 50K) + all working which needs to mount stations on the necessary places. One BSC can support more than one BTS, but we will consider the situation when one BSC will support one BTS. For our start-up network, we need 91 BTS, i.e., 91 BSS. Investment for cellular stations should be = 91 x 100000K = 9 100 000 K.10100000K. In a market one BSS cost is about 50,000 EURO and provided an amount of100000KUSD is not real. There are included costs of all necessary OSS (Operation and Support System) and SS (Switching System) hardware that will be needed for this BSS operating.Also included is the necessary infrastructure cost, per one BSS, for example, FO networks or wireless networks [10].

Now will estimate the additional investment, in 5 years, in the case when we will have to increase subscribers by 20% (60 000 subscribers). To provide service to an additional 20% of subscribers we can increase our network in a few ways:

- Every time, for every 20% additional subscriber, we will install additional BTS in those places where the network is overloaded. We will use the additional frequencies or bring it from reserved (3.2.2 Zone of transition). Also, we can reduce necessary cells' R, then will mount in the emerging "black holes" new BTS.
- Once increase capacity by 100% we will not do anything else, so far, the count of subscribers will be = 300 000 x 2 = 600 000.

For additional users (20% - 60 000) we should mount the additional stations. We will not mount a new BSC, new BTS, and new sectoring canbe managed by available BSC. We will mount new 60 000 1096 = about 55 new sectors/cells. Additional investment, in this case, will be = 55 x 50K = 2 750 K.In this case, we will not mount a new BSC also, we will reduce the size of our clusters by half and install additional 91 BTS, i.e., 91 x 3 = 273 new sectors.

Additional investment, in this case, will be = 273 x 50K = 13 650 K.

CONCLUSION

The goal of this research was to build a cellular network that would cover 1507 square kilometers of land in Tripoli, Libya, with a population of over three million. There are 83 clusters composed of 12 cells each and over a hundred radio channels. Each cluster has three sectors and four directional antennas. We provided a complete solution for the design and implementation of Tripoli City's cellular network, including the various stages of the design process, such as the planning of the network, the radio propagation, and the simulation of the network.

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