5 Cell planning

Objectives

After this chapter the student will be able to:

- discuss the relations between re-use distance, traffic capacity and speech quality.
- understand the different steps in the cell planning process.
- define C/I and C/A and state their limits in GSM.
- assign frequencies to different cells and calculate the received capacity.
- understand the procedure for estimating the cell coverage.

5.1 Introduction

Achieving maximum capacity whilst maintaining an acceptable grade of service and good speech quality is the main issue for the cellular network planner.

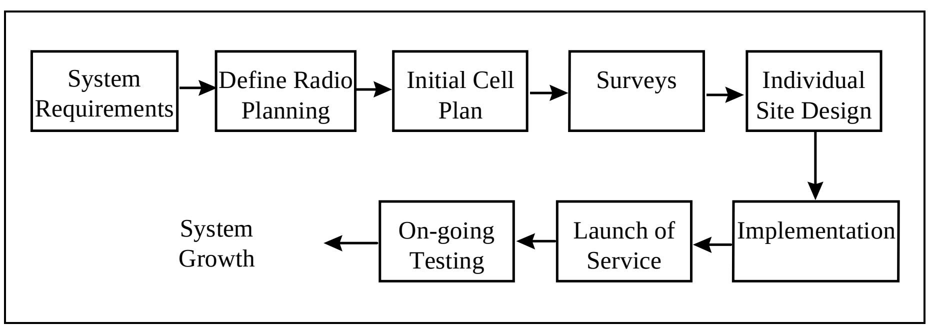
Planning an immature network with a limited number of subscribers is not the real problem. The difficulty is to plan a network that allows future growth and expansion. Wise re-use of site locations in the future network structure will save money for the operator.

In this chapter we will look at issues to consider when cell planning: cell types, re-use patterns, interference problems, channel assignment and cell size calculations.

5.2 Steps in the cell planning process

Cell planning means building a network able to provide service to the customers wherever they are. This work can be simplified and structured in certain steps. Some of these steps are performed frequently whilst others are more rare. Normally the output from one box is the input of another. A cell planner is most likely dealing with the content of several of these boxes at the same time.

The following describes the steps involved and the tasks to be performed at each step. This process is by no means complete or undebatable, each operator has its own flowchart of processes.



Different steps in the cell planning process

This process should not be considered just as it is depicted, in a single flow of events. For instance, the radio planning and surveying actions are interlinked in an ongoing iterative process that should ultimately lead to the individual site design.

System Requirements:

- Coverage for different customers in different environments
- Traffic behaviour of customers in different regions
- Phases of build-out
- Quality of Service, GOS and speech quality
- Expansion and future investments
- Limited available bandwidth

Define radio planning guidelines:

- Coverage and interference: which prediction model to use, fading margins for indoor, outdoor and in-car
- Traffic planning: choice of models and processes
- Frequency planning strategy: choice of reuse pattern and allocation of frequencies
- Testing and optimisation strategy

Initial cell plan:

- Idealised overview of site locations and BTS configurations
- Predicted composite coverage and interference map
- Cell configuration, parameter setting, channel loading plan, choice of combiners, system balance, antenna types, equipment type

Surveys:

- Radio environment survey:
  Investigate path loss, interference and time dispersion. Investigate other systems antennae and interfering transmitters.
- Site survey:
  Pinpoint exact location with GPS. The ideal planned locations have to be searched for any suitable building, tower or vacant lot that could be leased for a reasonable cost. Check space for antenna mounting, isolation, diversity, roof clearance (first Fresnel zone empty). Investigate physical necessities such as space for equipment, power and PCM links.

Individual site design and parameter setting:

- Radio engineers need to select best site location from the options available from the site acquisition department.
- Dimensioning of BTS, BSC, MSC and the access network.
- Antenna gain, direction and tilt and ERP need to be decided.
- Plan for allocating frequencies, BCCH and LAI.

Implementation:

- Install: BTS, power, termination equipment for PCM link, air-conditioning equipment, earth bar, lightning equipment and antennas. Adjust output power, set parameters.
- Commissioning tests of BTS. Drive testing to detect blank spots and interference and to confirm correct call set-up, handover, location updating and to detect missing neighbour relations.

Launch of commercial service:

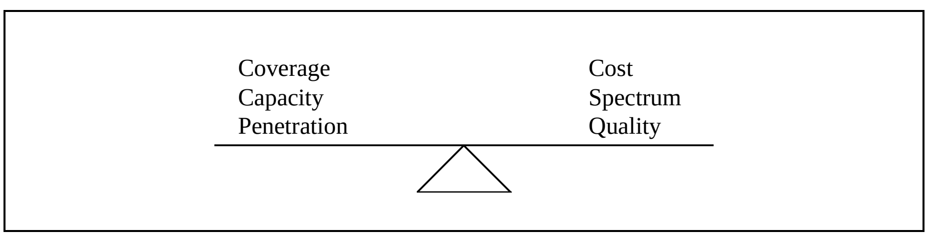
- When the network is operational a commercial launch can be made.

On-going testing, analyses and optimisation:

- System diagnostics: collect statistics in OMC, MSC or BSC to analyse traffic behaviour, traffic distribution, Grade of Service, call success rate, handover failures, dropped calls, radio channels quality, access links statistics, and to study trends.
- Drive testing to localise weak signal strength, interference, time dispersion or other radio problems. Also to investigate problems reported by customers and to validate changes undertaken such as frequency re-tuning or parameter settings .
- Analysis of the results above, and
- Optimisation of parameters, timers, physical implementation of antenna directions or tilts or any other measures to counteract detected problems.

5.3 Different cell types

A cellular network is created by means of placing equipment in strategic places to guarantee a certain perceived Quality of Service. Idealistic then would be to place a base station in every street corner, but this is not cost efficient. Which cell types to use must be weighed against cost and expected penetration.



The choice of cell types affecting several posts on the scale

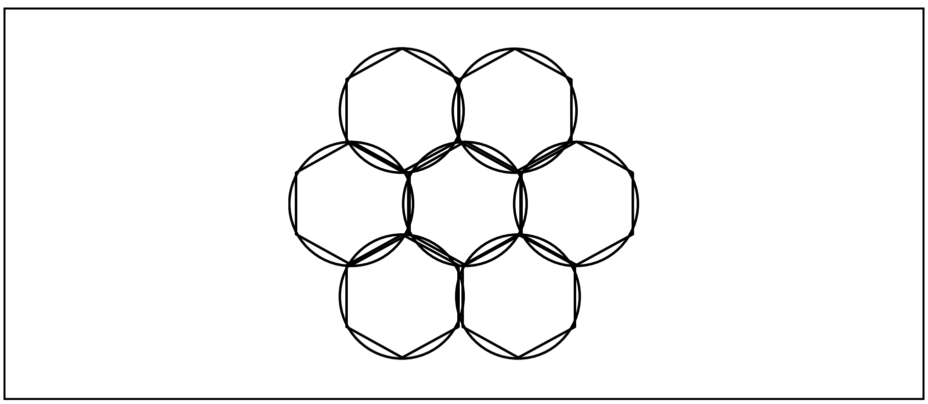
Important when designing a network is to find a balance regarding which combination of these three types of cells to use:

Macro cells have a typical coverage range from 1 to 35 km. Normally the site location is on a hilltop or a rooftop, guarantying good coverage. The main rays are propagated over the rooftops.

Micro cells have a typical coverage range from 0.1 to 1 km, where the major part of the radio waves is propagated along the streets. The base station antenna placement is below the rooftops of the surrounding buildings. A micro cell can maintain indoor coverage in the lower levels of a building.

Pico cells supplies coverage in indoor environment (or possibly outdoors in environments physically distinctly limited - a backyard e.g.). The base station is transmitting at low output power and the antennas could be mounted on walls or in the ceiling. Pico cells are used when the capacity need is extremely high in certain hot spots.

In the theoretical part of cell planning, base station coverage areas or cells are shown as hexagons. This is so because the system is designed to let the mobile always operate on the nearest or best base station. Thus, boundaries between the base station cells will theoretically form straight lines, perpendicular to the connection lines between the sites, and these will form a hexagonal cellular pattern.



Cell coverage shown as a hexagon

The use of different types of cells on the same area introduces the concept of a hierarchical structure, leading to increasingly complex handover relations and planning.

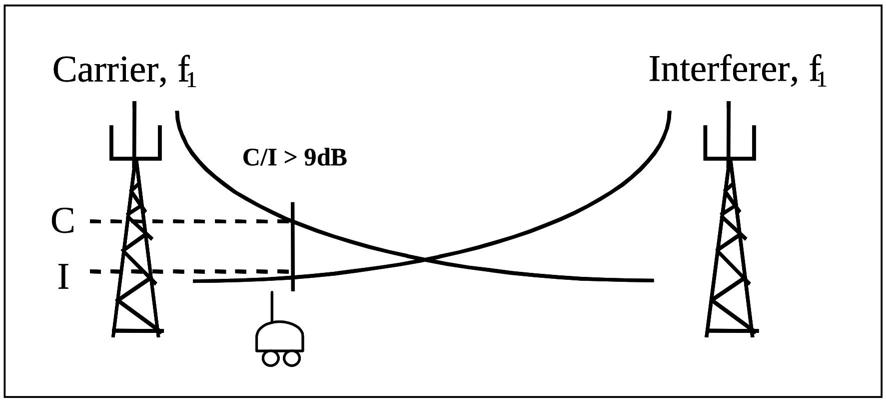
5.4 Interference and its effect on the re-use distance

The limited frequency band available introduces interference in the system, as the cell planners are forced to build up a network by means of clusters and frequency re-use. Distance between two co-channel sites decrease, meanwhile the rush of new subscribers increases, resulting in an increased overall interference in the network.

The following thresholds are defined in the specifications for a C (carrier) 20dB above the sensibility level. This means that in areas where this cannot be guaranteed, C/I ratios will be poorer, thus degrading system performance.

Co-channel interference, C/I

Reusing an identical carrier frequency in different cells is limited by co-channel interference or C/I. Co-channel interference is the relation between the desired signal C and the undesired re-used signal I, both using the same carrier frequency.



Co-channel interference

Suitable values for this ratio are settled by evaluation by a large group of listeners as to what is acceptable speech quality. The values given in the GSM recommendation are:

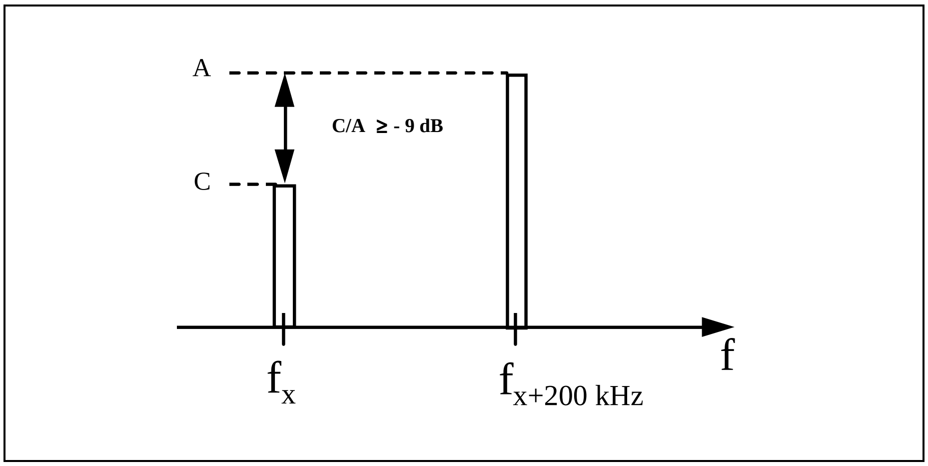
C/I ≥ 9 dB

The margin for Rayleigh fading is already included in this value. But when the value 9 dB was decided, frequency hopping was assumed. In phase 1A in the GSM specification, frequency hopping is not used and in that case the value 12 dB should be used instead of 9 dB. The use of space diversity reception will improve the C/I properties of the system as the problem with fading dips is reduced.

It should be mentioned that co–channel interference requires not only channels to be assigned to different cells but also that they are actually in use simultaneously. This means that interference will be more of a problem during busy hours than at other times.

Adjacent channel interference, C/A

As the filters, limiting each carrier to its domain of 200kHz, are not ideal, the carriers will somewhat affect each other. The relation between the desired signal C from the correct carrier and the undesired signal A from the carrier 200 kHz away is called adjacent channel interference or C/A.



Adjacent channel interference C/A

When a frequency re-use pattern such as the 3/9 pattern is used, adjacent frequencies will be used in neighbouring cells. This means that some of the energy of the adjacent frequency will leak into serving cell and cause interference. The limit for this ratio in GSM is:

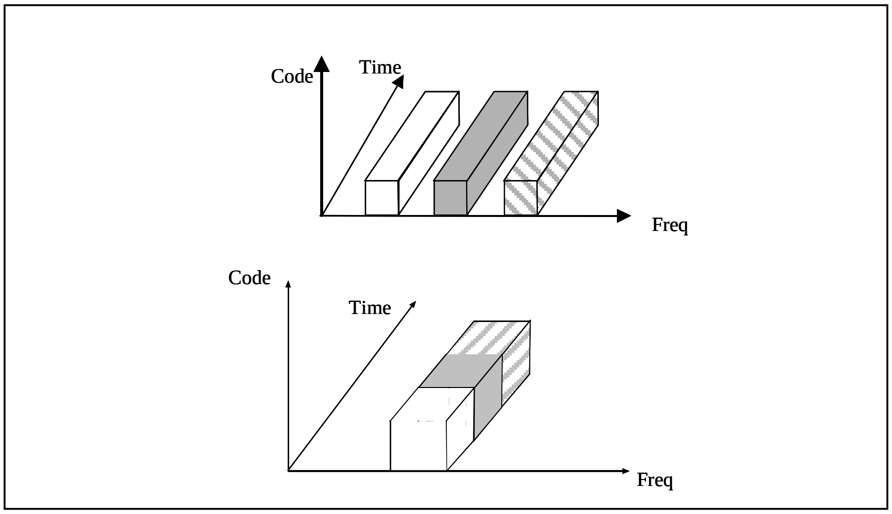
$C/A_1 \geq -9$ dB

This means that we can allow the adjacent carrier frequency A_1 to be up to 9 dB stronger than our desired signal C. The index in A_1 denotes that we are referring to the first adjacent channel, the one 200 kHz away.

The same reasoning can be applied to the second adjacent channel, the carrier 400 kHz away. In this case the second adjacent carrier frequency A_2 can be up to 41 dB stronger than our desired signal C. In other words, C/A_2 is not really an issue.

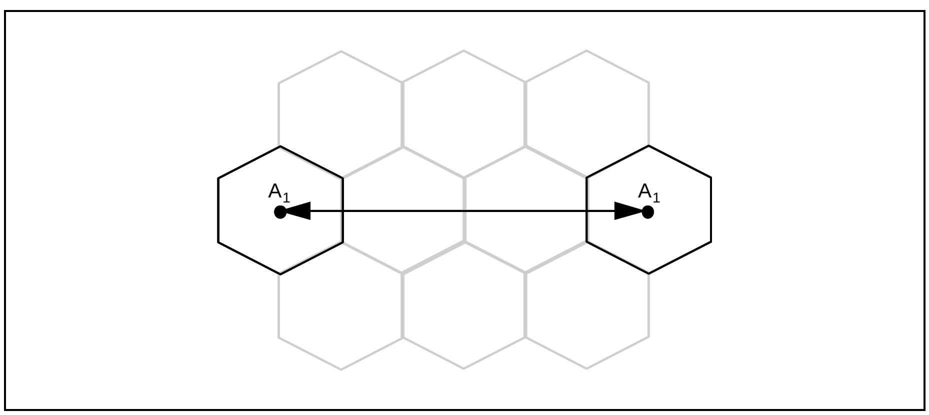
5.5 Frequency re–use

The second generation of cellular systems (GSM, digital AMPS, etc) is not necessarily more frequency efficient than the first generation of cellular systems (NMT, AMPS, TACS etc.). This is true if we look at how efficiently the frequency spectrum is used in one spot. GSM needs 200 kHz to fit 8 physical channels, NMT and AMPS both need roughly the same bandwidth for the same number of channels.



Frequency efficiency in a TDMA system versus a FDMA system

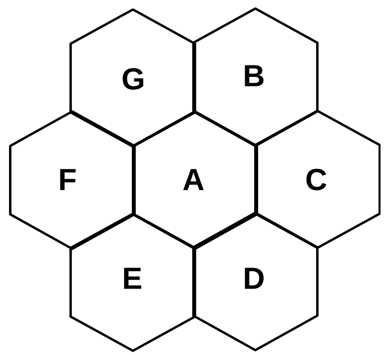
A frequency used in one cell can be re-used in another cell at a certain distance. This distance is called re-use distance. The advantage of digital systems is that they can re-use frequencies more efficiently than the analogue ones, i.e. the re-use distance can be shorter, and the capacity increased.



Frequency re-use

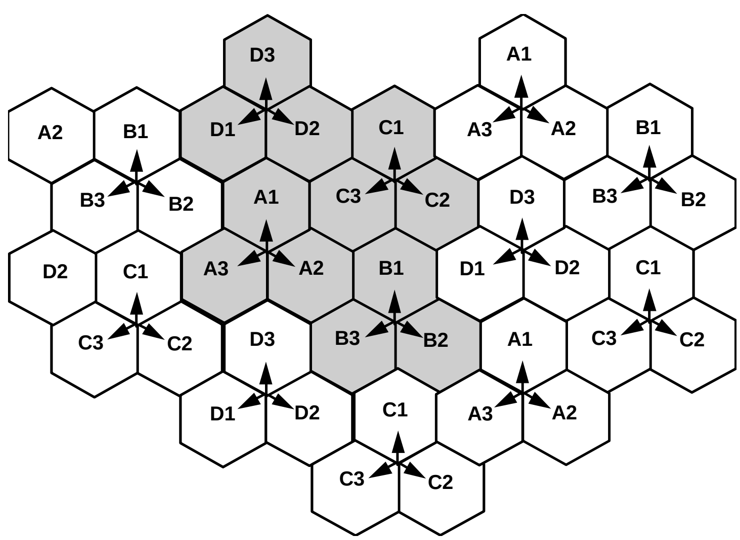
A cellular system is based on re-use of frequencies. All the available frequencies are divided into different frequency groups so that a certain frequency always belongs to a certain frequency group. The frequency groups together form a cluster. A group of neighbouring cells using all the frequencies available in the system frequency band is called a cluster of cells. By repeating the cluster over and over again a cellular network can be built.

A cluster is an area in which all frequency groups are used once, but not re-used.



Frequency groups forming a cluster

The frequencies can be divided into different frequency groups. This introduces the terms re-use patterns and re-use grids. The most common re-use patterns in GSM is "4/12" and "3/9".



4/12 frequency re-use pattern

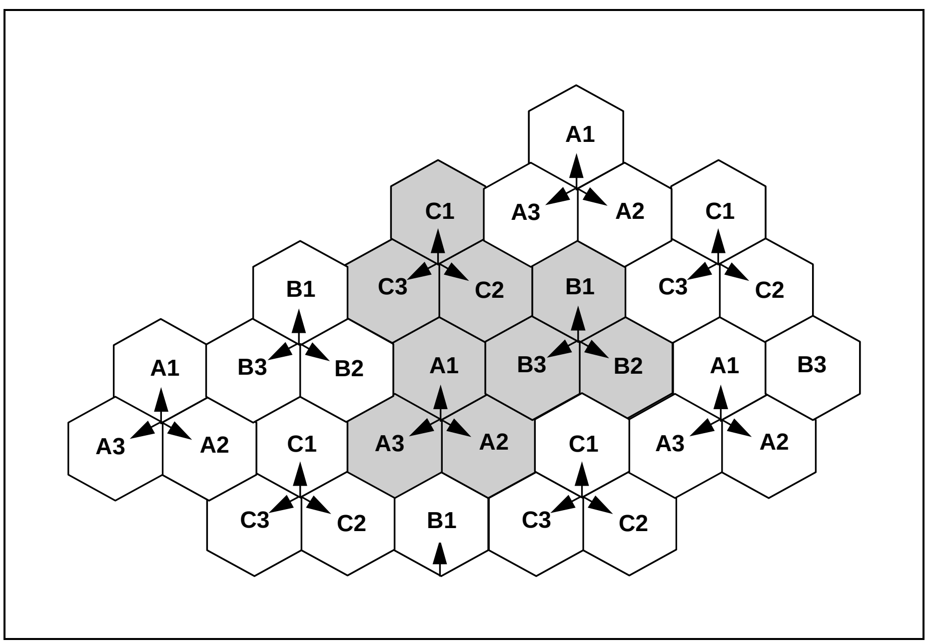
4/12 means that the available frequencies are divided into 12 frequency groups, which in turn are located at 4 base stations sites. This assumes that the base station has three cells connected to it. The frequency groups are often assigned a number or name such as A1, B1, C1, D1, A2, ..., D3.

3/9 means that the available frequencies are divided into 9 frequency groups located at 3 sites. Problems with C/A might appear in certain parts of a cell, arising from adjacent frequencies in neighbouring cells.

<u>Example:</u> Channel assignment of 24 frequencies in a 3/9 cell plan.

Frequency groups	A1	B1	C1	A2	B2	C2	A3	B3	C3
Channels	1	2	3	4	5	6	7	8	9
	10	11	12	13	14	15	16	17	18
	19	20	21	22	23	24			

The channel numbers used within a cell are always 9 channels apart. This is beneficial since the transmitter combiner must have a specified channel separation between the carrier frequencies to combine. It also eliminates the risk of possible adjacent channels interference within a cell which could otherwise take place.



3/9 frequency re-use pattern

Other ways to build up a network exists besides the 4/12 and 3/9 reuse pattern.

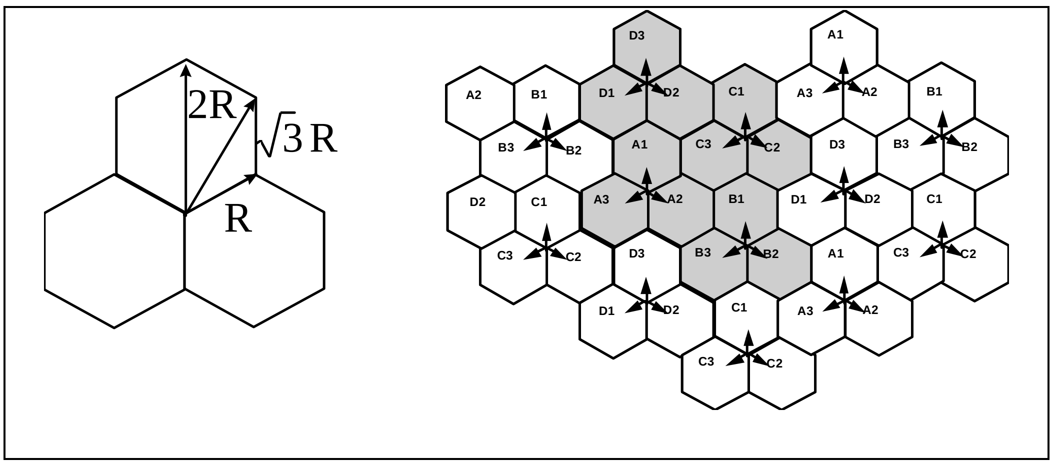
C/I affecting re-use distance

It is easy to see that at a given cell size the re–use distance will depend only on the number of frequency groups ”N", which is used in the frequency re–use pattern. The lower number of frequency groups "N", the shorter the re-use distance, and the more compressed the network will be. Capacity will increase but the interference from surrounding neighbouring co-channel sites will also increase. The C/I requirement that is decided or specified therefore decides which re-use pattern to use. Variations of 10 dB between an analogue system and a digital are not unusual.

The first step in order to determine ”N" would be to calculate the ratio D/R between co–channel cells, or sites. From geometrical relations the ratio D/R is found to be:

$$\mathbf{D/R = \sqrt{3N}}$$

where R is the cell radius.



Relation between R and a hexagon

If N is determined, D (co–channel distance) can be calculated. The co–channel distances in each of the two cases, 3/9 and 4/12, are:

3/9: D = 5.2 R
4/12: D = 6 R

(As a reference, most analogue systems used the 7/21 frequency re-use pattern, where D=7.9R.)

A sector–cell normally suffers interference from a smaller number of interfering cells than an omni, which can suffer interference from all directions. Ultimately the coverage range from the base will be limited by these rather than by the noise. Thus, we say that a mature cellular system is interference limited rather than noise limited. Keeping this interference below a certain level is done partly by controlling the channel re–use distance. The larger D is, the less is the interference.

Reflected channel interference or C/R is the relation between the signal strength of the desired signal C and the reflected signal R. This phenomenon is referred to as time dispersion. Actually, there is no difference in interference caused by co-channel interference or by reflected channel interference. The result is the same: energy disturbing our desired signal in the very same frequency domain. This disturbances might effect the possible re-use distance in the same way as C/I

5.6 Capacity calculation for cellular network

One starting point when designing a cellular network is the estimation of traffic. To be able to offer a certain traffic capacity with a certain quality, some kind of statistical model to figure out the number of required channels is needed. When dealing with GSM we need to handle not only traffic capacity, but also the capacity of the control channels needed to set up the call. Traffic theory gives us a chance to calculate on traffic, and from the results base our dimensioning of the network. The calculations should be based on the busy hour of the network.

Definition of traffic

When estimating the traffic offered by one subscriber, the call intensity $\boldsymbol{\gamma}$ and the average duration $\boldsymbol{\tau}$ of each call are essential. One way of defining traffic is this:

$$A_{SUB} = \frac{\gamma \times \tau}{3600} \ [E]$$

A_{SUB} = traffic from one subscriber
γ = number of calls per hour per subscriber
τ = average call duration

Typical values could be:

γ: 1
τ: 120 seconds

$$A_{SUB} = \frac{1 \times 120}{3600} = 33 \text{ mE}$$

If the number of subscribers is 1000, a total traffic of 33 E would be generated.

$$A_{TOT} = 1000 \times \frac{1 \times 120}{3600} = 33\ E$$

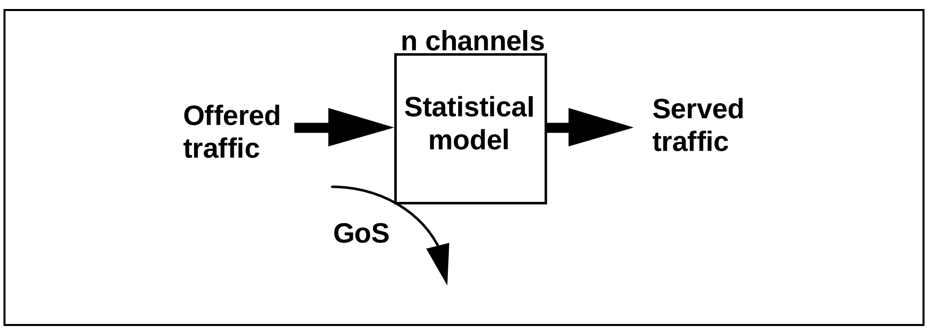
Traffic is measured in the unit Erlang. One Erlang corresponds to one line being occupied 100% during one hour.

Models for traffic calculations

First some definitions of different types of traffic;

- Carried or served traffic is the traffic that is successfully carried or served by the system.
- Offered traffic is the traffic offered by the subscribers wanting to use the system. This is the amount of traffic that would take place if the number of devices were so large so that no calls were rejected.
- Rejected traffic is the traffic that is blocked due to lack of system capacity. The probability of a call to be blocked is called Grade of Service or GoS. To be absolutely certain that no calls are blocked, each subscriber would need his or her own private line or traffic channel! Of course, we cannot justify a network like that. Therefore networks are designed for different probabilities of blocking. Most GSM-operators use a GoS between 1 and 5 %.

If we have an estimate for the total traffic to be handled by the system, that is the offered traffic, and for the GoS, we need a statistical model to find out the number of traffic channels needed for the task.



Traffic model

Erlang B, also called the first formula of Erlang, is the model most commonly used for this purpose. In this formula the following is assumed;

- Full availability, i.e. no calls are blocked until all devices are busy
- The number of callers >> the number of devices

- No queues, i.e. a blocked call will not be repeated
- Call attempts are randomly distributed
- Exponential distribution of call duration

The relation between the three components, n, A and GoS, are here shown for certain values in the Erlang B table on the next page:

	Grade of Service (GOS)							
	1,0%	**2,0%**	**3,0%**	**4,0%**	**5,0%**	**10,0%**	**20,0%**	**40,0%**
1	0,01010	0,02041	0,03093	0,04167	0,05263	0,11111	0,25000	0,66667
2	0,15259	0,22347	0,28155	0,33333	0,38132	0,59543	1,0000	2,0000
3	0,45549	0,60221	0,71513	0,81202	0,89940	1,2708	1,9299	3,4798
4	0,86942	1,0923	1,2589	1,3994	1,5246	2,0454	2,9452	5,0210
5	1,3608	1,6571	1,3608	2,0573	2,2185	2,8811	4,0104	6,5955
6	1,9090	2,2759	2,5431	2,7649	2,9603	3,7584	5,1086	8,1907
7	2,5009	2,9354	3,2497	3,5095	3,7378	4,6662	6,2302	9,7998
8	3,1276	3,6271	3,9865	4,2830	4,5430	5,5971	7,3692	11,419
9	3,7825	4,3447	4,7479	5,0796	5,3702	6,5464	8,5217	13,045
10	4,4612	5,0840	5,5294	5,8954	6,2157	7,5106	9,6850	14,677
11	5,1599	5,8415	6,3280	6,7272	7,0764	8,4871	10,857	16,314
12	5,8760	6,6147	7,1410	7,5727	7,9501	9,4740	12,036	17,954
13	6,6072	7,4015	7,9667	8,4300	8,8349	10,470	13,222	19,598
14	7,3517	8,2003	8,8035	9,2977	9,7295	11,473	14,413	21,243
15	8,1080	9,0096	9,6500	10,174	10,633	12,484	15,608	22,891
16	8,8750	9,8284	10,505	11,059	11,544	13,500	16,807	24,541
17	9,6516	10,656	11,368	11,952	12,461	14,522	18,010	26,192
18	10,437	11,491	12,238	12,850	13,385	15,548	19,216	27,844
19	11,230	12,333	13,115	13,755	14,315	16,579	20,424	29,498
20	12,031	13,182	13,997	14,665	15,249	17,613	21,635	31,152
21	12,838	14,036	14,885	15,581	16,189	18,651	22,848	32,808
22	13,651	14,896	15,778	16,500	17,132	19,692	24,064	34,464
23	14,470	15,761	16,675	17,425	18,080	20,737	25,281	36,121
24	15,295	16,631	17,577	18,353	19,031	21,784	26,499	37,779
25	16,125	17,505	18,483	19,284	19,985	22,833	27,720	39,437
26	16,959	18,383	19,392	20,219	20,943	23,885	28,941	41,096
27	17,797	19,265	20,305	21,158	21,904	24,939	30,164	42,755
28	18,640	20,150	21,221	22,099	22,867	25,995	31,388	44,414
29	19,487	21,039	22,140	23,043	23,833	27,053	32,614	46,074
30	20,337	21,932	23,062	23,990	24,802	28,113	33,840	47,735
31	21,191	22,827	23,987	24,939	25,773	29,174	35,067	49,395
32	22,048	23,725	24,914	25,890	26,746	30,237	36,295	51,056
33	22,909	24,626	25,844	26,844	27,721	31,301	37,524	52,718
34	23,772	25,529	26,776	27,800	28,698	32,367	38,754	54,379
35	24,638	26,435	27,711	28,758	29,677	33,434	39,985	56,041
36	25,507	27,343	28,647	29,718	30,657	34,503	41,216	57,703
37	26,378	28,254	29,585	30,680	31,640	35,572	42,448	59,365
38	27,252	29,166	30,526	31,643	32,624	36,643	43,680	61,028
39	28,129	30,081	31,468	32,608	33,609	37,715	44,913	62,690
40	29,007	30,997	32,412	33,575	34,596	38,787	46,147	64,353
41	29,888	31,916	33,357	34,543	35,584	39,861	47,381	66,016
42	30,771	32,836	34,305	35,513	36,574	40,936	48,616	67,679
43	31,656	33,758	35,253	36,484	37,565	42,011	49,851	69,342
44	32,543	34,682	36,203	37,456	38,557	43,088	51,086	71,006
45	33,432	35,607	37,155	38,430	39,550	44,165	52,322	72,669
46	34,322	36,534	38,108	39,405	40,545	45,243	53,559	74,333
47	35,215	37,462	39,062	40,381	41,540	46,322	54,796	75,997
48	36,109	38,392	40,018	41,358	42,537	47,401	56,033	77,660
49	37,004	39,323	40,975	42,336	43,534	48,481	57,270	79,324
50	37,901	40,255	41,933	43,316	44,533	49,562	58,508	80,988
51	38,800	41,189	42,892	44,296	45,533	50,644	59,746	82,652
	1,0%	**2,0%**	**3,0%**	**4,0%**	**5,0%**	**10,0%**	**20,0%**	**40,0%**

The Erlang B table

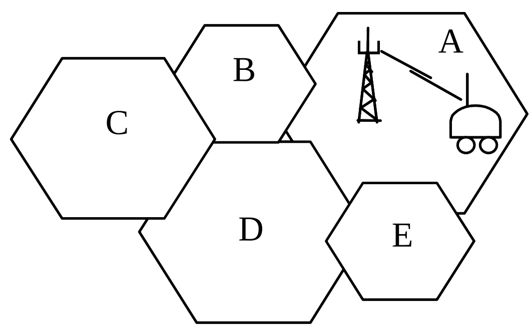
Example: If the number of available channels (TCH:s) is 15, the GoS required is 2 %, the offered traffic we can take care of is found in the Erlang table. 9.0096 E can be handled in that case.

Another model is the Erlang C, also called the second formula of Erlang. The main difference is that in this so called queue model the subscriber will wait until a device is available independently of how long. This model will give us a slightly lower traffic capacity.

Dimensioning a cellular network

The subscribers in a small town generates a total offered traffic of 33 Erlang. Assume the task is to find the necessary number of channels per cell, in order to cover this traffic demand. If the grade of service requirements during busy hour are 2%, the Erlang table gives that 43 channels will be enough! That would require 6 frequencies in one cell, which isn't possible due to the correlation between cluster size and available frequency band. Instead, we assume that the coverage requirement indicates that 5 cells are needed. Those cells must together offer the system 33 Erlang, with an acceptable grade of service of 2 %.

First, the total traffic is divided among the cells. This division must be defined by the customer or made from reasonable assumptions. Let us assume the following traffic distribution:



Cell	% Traffic	A_{TOT} in Erlang	No. of channels	No. of frequencies
A	40	13.20	20	3
B	25	8.25	14	2
C	15	4.95	10	2
D	10	3.30	8	2
E	10	3.30	8	2
Σ cells	100	33.00	60	11

Traffic distribution divided between different cells in an area

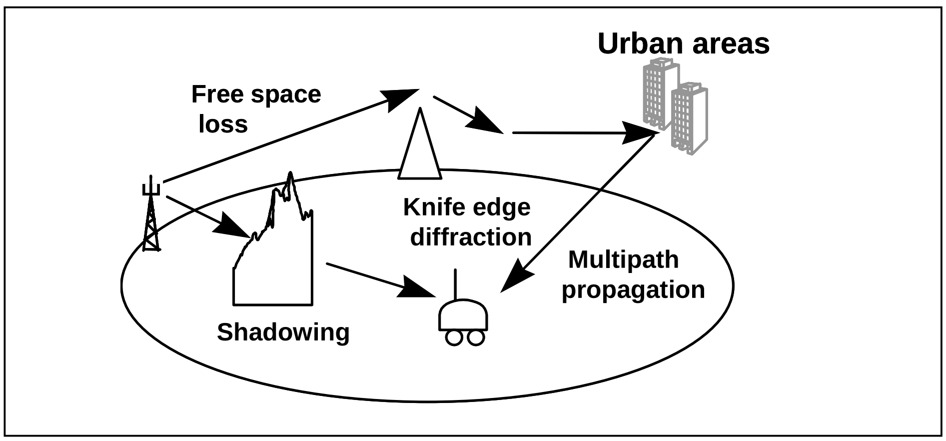
As shown above, traffic distribution over several cells results in more necessary channels than if all traffic had been concentrated to one cell.

Unfortunately, after having calculated the traffic and found a channel requirement, the number of TCHs needed will probably not correspond exactly to the number of frequencies allocated. Each new frequency carries 8 physical channels which all comes in a bunch at allocation.

5.7 Coverage calculation in a cellular network

Assuming that the traffic calculations has shown that the capacity is not a problem in the cell. Then there is time to look closer at the possibility of having a coverage restricted system. For this we need a model to be able to predict the propagation path loss Lp on the radio link between Base Transceiver Station (BTS) and Mobile Station (MS).

During one single call, the MS experiences such a complex variety of superimposing and transitory *shadowing*, *absorption* and *scattering* effects that there is no exact solution to the problem of finding Lp.



Changes in the radio environment affect path loss

The remaining available approach is therefore to use statistical distributions to describe the radio environment. In doing so, most propagation models deal only with the prediction of the median value for Lp, its variability being accounted for with the use of different fading margins for different environments.

If done manually, propagation calculations are quite time consuming. Normally they would be handled by computer-based prediction tools. Coverage predictions can be seen as the basic platform upon which the planning tool enables the Cell Planner to do all kinds of post processing analysis, from the most straightforward interference and traffic analysis, to more complex simulations of the GSM system.

To be able to find out how many cells that are needed to cover a certain area, we need to calculate the approximate size of the cells. This is done by estimating how far out from the BTS that the radio waves can reach, still strong enough for a MS on the cell border. At this stage it would be easy to just install a couple of BTSs with high output power, strong enough to give good signal strength (i.e coverage) everywhere. The problem would then be a weak uplink, since the MSs have a limited output power and would not be able to reach all the way back to the BTS.

Thus, we have to start with balancing the system so that both uplink and downlink are equally strong. That is done by calculating an appropriate output power from the BTS, considering the limited output power from the MS. After that we would like to estimate the range of the radio waves. To be able to do that we need to specify how strong signals we would like the MS to receive on the cell border, to maintain calls and signalling procedures. Since the radio waves have to overcome all sorts of shadowing obstacles (buildings, structures, trucks etc) as well as reflections from the surroundings, the resulting radio signal will vary a lot. To make sure that the MS will experience a good enough signal at all times, we add margins to our calculations of the required signal strength at the cell border.

When the output power from the BTS is known, with respect to the balance, and the required signal strength at the cell border is calculated, we know the maximum allowed loss of signal strength from the BTS to the cell border. That gives us the possibility to “translate” that into a distance from the BTS to the cell border (which is a measure of the cell size we wanted from the beginning), by using a radio wave propagation model. These different models, applicable for different cell types and environments, gives us mathematical relations between signal strength loss (i.e “path loss”) and distance, so that we can find out how far out from the BTS we can have the cell border.

All this is of course done with the help of a computer based prediction tool to be able to come up with an initial cell plan (third step in the cell planning process shown).