Implementation of Mobile Measurement-based Frequency Planning in GSM

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Abstract

The large number of subscribers in the network and the increasing usage of existing mobile telephony services together with upcoming new services, such as video and audio streaming, will force operators to significantly increase capacity offered by the network.. Sectorisation and cell splitting, two standard methods to increase capacity from macrocells. Often operators also utilise advanced network features to reduce the frequency reuse factor and thus further increase network capacity of macro cells. Owing to the limited spectrum and because of HW constraints regarding channel separation required on a cell or a site basis, providing additional capacity from existing macro cells is often impossible without degrading call quality. Therefore, network operators also have to use alternative cell types such as micro cells to meet capacity requirements. The reduced cell sizes also create new challenges. The main challenge is frequency planning. This paper presents implementation of mobile measurement-based frequency planning.

1. Introduction

Operators can increase the capacity of existing cells with additional hardware equipments to provide extra resources for additional requests. Hardware equipments are often transceiver units called TRX. Each TRX in the network requires at least one frequency to operate. As the number of frequencies that an operator has been allocated is far smaller than the number of TRXs in the network, it is required to repeat the use of a frequency several times throughout the network.. For example, in a network consisting of 20000 TRXs using 50 channels, each channel has to be reused about 400 times [1].

Owing to the limited spectrum and because of HW constraints regarding channel separation required on a cell or a site basis, providing additional capacity from existing cells is often impossible without degrading call quality [1]. Frequency assignment process is very important. There must be no interference between sectors of the same site. Furthermore, assigned frequencies shouldn't increase acceptable interference level in neighbour cells.

Although TRXs are added, capacity can be still insufficient. In this situation, network operators have to use alternative cell types such as micro cells and in-building cells to meet capacity requirements. Owing to the fact that in a city centre environment the distance between macro sites of an operator is typically as low as 300 m and that several operators are competing for new sites, suitable locations to establish additional cells are very difficult to obtain.

Cell coverage areas are not homogeneous. Different coverage areas can intersect, in other words cells are partially overlapping. If same or adjacent frequencies are used in such cells, the interference will occur in intersecting areas. Call quality in such areas is often degraded. Sometimes subscribers cannot make a successful call attempt.

The operator of a cellular system is given a frequency band to use in the area. This spectrum is divided in a number of carriers. An operator has average 50 channels and a GSM radio network can include hundreds of cells in a city. Thousands of channels should be assigned to these cells. Therefore the carriers can be reused within an area. It should be given the most appropriate frequencies according to neighbour relations of cells. An interference matrix is required for assignment of appropriate frequencies (Figure 1).

Each call made by the subscribers in the area to be planned contributes to the interference matrix. This interference matrix reflects exactly where and when subscribers make calls.

As proof of concept, we have implemented a frequency planning application that uses mobile measurement-based interference matrix and determines appropriate frequencies for cells.

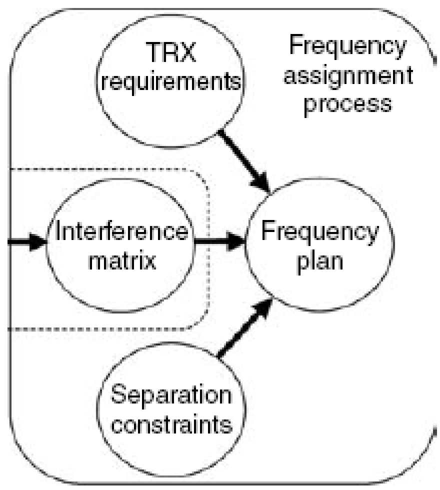


Figure 1: Frequency assignment process [1].

2. Cell Shape

In mobile networks we talk in terms of 'cells'. One base station can have many cells. Cells using the same site are called co-sited. These cells are served by sector antennas. In general, a cell can be defined as the area covered by one sector. The hexagonal nature of the cell is an artificial shape. This is the shape that is closest to being circular, which represents the ideal coverage of the power trasmitted by the base station antenna. The circular shapes are themselves inconvenient as they have overlapping areas of coverage; but, in reality, their shapes look like the one shown in the 'practical' view in Figure 2. A practical network will have cells of nongeometric shapes, with some areas not having the required signal strength for various reasons [2].

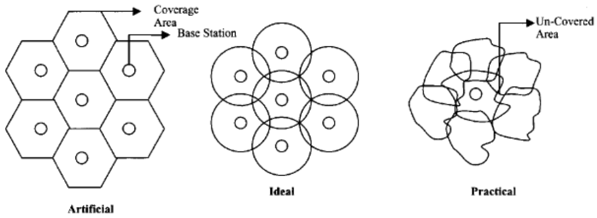


Figure 2: Cell shapes [2].

3. Channel Concepts

GSM 900 uses the frequencies 890-915 MHz for uplink and 935-960 MHz for downlink. These two frequency bands with a bandwidth of total 2*25 MHz is divided into 2*124 frequencies spaced 200 kHz apart.

Time Division Multiple Access (TDMA) is used in GSM for radio transmission. Each of 124 carriers is divided in 8 timeslots. The mobile station (MS) sends and receives at same timeslot. Therefore, that is possible to make eight different calls in same channel at same time.

Each timeslot on a TDMA frame is called a physical channel (Figure 3). Therefore, there are 8 physical channels per carrier frequency in GSM. Physical channels can be used to transmit speech, data or signaling information [3].

A physical channel may carry different messages, depending on the information which is to be sent. These messages are called logical channels. For example, on one of the physical channels used for traffic, the traffic itself is transmitted using a Traffic Channel (TCH) message, while a handover instruction is transmitted using a Fast Associated Control Channel (FACCH) message [3].

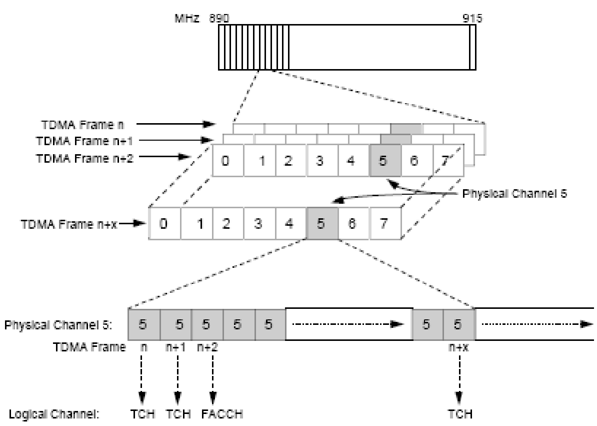


Figure 3: The TDMA channel concept [3].

3.1. Logical Channels

Many types of logical channels exist (Figure 4), each designed to carry a different message to or from an MS. All information to and from an MS must be formatted correctly, so that the receiving device can understand the meaning of different bits in the message. For example, in the burst used to carry traffic, some bits represent the speech or data itself, while others are used as a training sequence [3]. Logical channels are shown in the Figure 4.

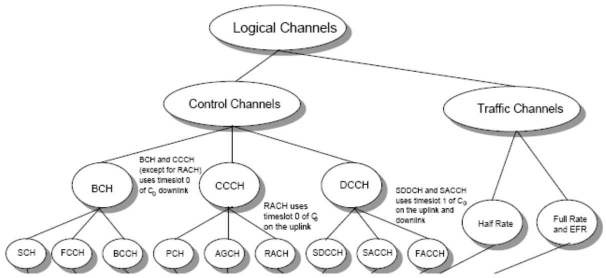


Figure 4: Logical channels [3].

3.2. Control Channels

When an MS is switched on, it searches for a Base Transceiver Station (BTS) to connect to. The MS scans the entire frequency band, or, optionally, uses a list containing the allocated carrier frequencies for this operator. When the MS finds the strongest carrier, it must then determine if it is a control channel. It does so by searching for a particular logical channel called Broadcast Control Channel (BCCH).

A frequency carrying BCCH contains important information for an MS, including e.g. the current LA identity, synchronization information and network identity [3]. Without such information, an MS cannot work with a network. This information is broadcast at regular intervals, leading to the term Broadcast Channel (BCH) information.

When the MS has finished analyzing the information on a BCH, it then has all the information required to work with a network. However, if the MS roams to another cell, it must repeat the process of reading FCCH, SCH and BCCH in the new cell. These logical channels are usually located in the first timeslot of a TRX. There must be only one BCCH per cell. The re-use of the BCCH TRX frequency should be greater than that of the other logical channels, since it should be the most interference-free.

If the mobile subscriber then wishes to make or receive a call, the Common Control Channels (CCCH) must be used. At this stage the MS and BTS are ready to begin call set-up procedures. For this the MS and BTS use Dedicated Control Channels (DCCH).

3.3. Traffic Channels

Once call set-up procedures have been completed on the control physical channel, the MS tunes to a traffic physical channel. It uses the Traffic Channel (TCH) logical channel. There are two types of TCH:

- Full rate (TCH): transmits full rate speech (13 kbits/s). A full rate TCH occupies one physical channel.
- Half rate (TCH/2): transmits half rate speech (5.6 kbits/s). Two half rate TCHs can share one physical channel, thus doubling the capacity of a cell.

3.4. Mapping of Logical Channels

Logical channels are transmitted on physical channels. The method of placing logical channels on physical channels is called mapping. While most logical channels take only one timeslot to transmit, some take more. If so, the logical channel information is carried in the same physical channel timeslot on consecutive TDMA frames.

Because logical channels are short, several logical channels can share the same physical channel, making the use of time slots more efficient.

The Figure 5 shows the carrier frequencies for a sample cell, including an additional allocation of a timeslot for DCCH information due to a high call set-up load in the cell.

Carrier Frequency \ Time slot	0	1	2	3	4	5	6	7
0	B,C	D	T	T	T	T	T	T
1	T	T	T	T	T	T	T	T
2	T	T	T	T	T	T	T	T
3	D	T	T	T	T	T	T	T

Legend:
B: BCH
C: CCCH
D: DCCH
T: TCH

Figure 5: Mapping of control and traffic logical channels to physical channels[3].

Timeslot 0 of the first carrier frequency in a cell is always reserved for signalling purposes. In this way, when an MS is determining whether a carrier frequency is a BCCH carrier, it knows where to look.

On the downlink, BCH and CCCH information is transmitted. The only logical channel on the uplink is RACH. By having the uplink free for RACH only, a mobile subscriber can initiate a call at any time.

Generally, time slot 1 of the first carrier frequency in a cell is also reserved for signaling purposes. The only exceptions to this are in cells with high or low traffic loads. As can be seen in Figure 5, if there is a high traffic load in a cell, it is possible to assign a third physical channel for the purpose of call set-up using DCCH. This may be any physical channel other than 0 and 1 on carrier frequency 0.

Similarly, if there is a low traffic load in a cell, it is possible to use physical channel 0 on carrier frequency 0 for all signaling information: BCH, CCCH and DCCH. By doing so, physical channel 1 can be freed up for traffic [3].

Eight SDCCHs and eight SACCHs can all share the same physical channel. This means that eight calls can be set-up simultaneously on one physical channel.

All time slots in a cell other than those assigned for signaling information are used for traffic, i.e. speech or data. Logical channel TCH is used for this.

In addition, at regular intervals during a call, an MS transmits to the BTS measurements it has made about signal strength and quality. Logical channel SACCH is used for this, replacing one TCH time slot at a time.

4. Traffic

Cellular system capacity depends on a number of different factors. These include:

- The number of channels available for voice and/or data
- The grade of service the subscribers are encountering in the system

Traffic theory attempts to obtain useful estimates, e.g. the number of channels needed in a cell. These estimates depend on the selected system and the assumed or real behavior of the subscribers [4].

Traffic refers to the usage of channels and is usually thought of as the holding time per time unit or the number of "call hours" per hour for one or several circuits[3]. Traffic is measured in Erlangs(E). One Erlang (1 E) is defined as the amount of traffic generated by the user when he or she uses one traffic channel for one hour [2]. In other words, if one subscriber is continuously on the telephone, this would generate one call per hour or 1 E of traffic.

Traffic can be calculated with the following formula:

$$A = \frac{n \times T}{3600} \tag{1}$$

Where, A = offered traffic from one or more users in the system, n = number of calls per hour, T = average call time in seconds.

Carried traffic by one cell depends on the number of traffic channels available and the amount of congestion which is acceptable, the so-called Grade of Service (GoS). There are different assumptions on subscriber behavior. A Danish traffic theorist Erlang's B-table is based on the most common assumptions used. These assumptions are:

- No queues
- Number of subscribers much higher than number of traffic channels available
- No dedicated traffic channels
- Poisson distributed traffic
- Blocked calls abandon the call attempt immediately

This is referred to as a "loss system". Erlang's B-table relates the number of traffic channels, the GoS, and the traffic offered.This relationship is tabulated in Figure 6. Assuming that one cell has two carriers, corresponding typically to 2x8=16 timeslots, 16 – 2 (for signalling) = 14 traffic channels and a GoS of %2 is acceptable, the traffic that can be offered is A=8.2003 E (Figure 6).

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

Figure 6: Part of Erlang's B table [4]

5. Mobile Measurement-based Frequency Planning

A mobile is not only receiving a signal from the closest base station, but the mobile also receives signals from other base stations further away that are sending on the same frequency. This is called co-channel interference. An adjacent channel is a channel that uses an adjacent frequency. It does not interfere as much as a co-channel. Since the number of frequencies is quite limited the frequencies have to be reused and problem with interference occurs. Frequency planning is required to minimise the interference.

An Inter-cell dependency matrix (ICDM) is required for mobile measurement-based frequency planning. The ICDM is calculated using measurement reports (BA list).

5.1. BA List and Handover

A BA (BCCH Allocation) list is a list sent from the base station to the mobile. This provides the mobile with suitable BCCHs to perform measurements on. The mobile returns a report to the base station that contains signal strength and the corresponding BSICs (Base Station Identity Codes) of these BCCHs it has measured. BSIC is used to identify which base station the BCCH comes from. When a mobile moves away from a base station the signal strength is decreasing and when it comes close enough to another base it changes to this new base station. This is called handover. BA reports are used to suggest candidates when the base station should perform handover.

5.2. ICDM (Inter-Cell Dependency Matrix)

Inter-Cell Dependency Matrix (ICDM) is a matrix where the elements represent how much in percent one cell is interfered by another. The ICDM is actually a multidimensional array where each of these elements contains tree values. One that says how much a co-channel in another cell is interfering. The second is the same for adjacent channels.

The BA-lists are varied and after a while all BCCHs are measured on. For all BCCHs in the BA-list the signal strength is measured and the BSIC is decoded. If the decoding is successful the mobile sends the information about the measured signal strength ($SS_{measured}$), own signal strength (SS_{own}) and base station identity to its base station. If SS_{own}–$SS_{measured}$ is less than a given limit in dB the base station is a potential interferer. If the own base station uses the same frequency it is a real interferer.

5.3. Implementation

In this section, an implementation of mobile measurement-based frequency planning is presented.

We have developed a software that uses mobile measurements and generates an appropriate frequency plan. A cell table and an inter cell dependency matrix (ICDM) is needed as input for frequency planning process.

The cell table includes "Cell", "Carriers Required" and "Busy hour Traffic (E)" columns (Table 1). "Cell" column shows cell names. "Carriers Required" column shows that how many channels will be assigned and "Busy hour Traffic (E)" column shows maximum hourly traffic of a cell during one day.

Table 1: Cell table for frequency planning

Cell	Carriers Required	Busy hour Traffic (E)
AHMTL1	2	3.8654
AHMTL2	5	26.8889
TURDA2	4	19.5540
TURDA1	5	23.3690
AKBAL1	3	9.8557

ICDM table includes "Source Cell", "Interferer Cell", "Co-Channel Interfered Traffic(%)" and "Adjacent Channel Interfered Traffic(%)" columns (Table 2). "Source Cell" column shows cells which serve to mobile subscribers during recording of mobile measurements. "Interferer Cell" column shows cells which can interfer source cell if same or adjacent channel is assigned to them. "Co-Channel Interfered Traffic(%)" column shows interefered traffic percentage of source cell if same channel is assigned to interferer cell. "Adjacent Channel Interfered Traffic(%)" column shows interefered traffic percentage of source cell if adjacent channel is assigned to interferer cell.

Table 2: Inter Cell Dependency Matrix (ICDM)

Source Cell	Interferer Cell	Co-Channel Interfered Traffic(%)	Adjacent Channel Interfered Traffic(%)
AHMTL2	AKBAL1	0.38	0
AHMTL2	TURDA1	11.46	3.09
AHMTL2	TURDA2	7.24	0.7
AHMTL2	AHMTL1	80.62	41.44
AHMTL1	TURDA1	2.58	0
AHMTL1	TURDA2	0.54	0
AHMTL1	AHMTL2	50.15	13.89
AKBAL1	AHMTL1	3.45	0.23
AKBAL1	TURDA1	30.24	9.48
AKBAL1	TURDA2	10.03	2.77
TURDA1	AHMTL2	5.37	1.29
TURDA1	TURDA2	45.21	15.61
TURDA2	AHMTL2	12.82	4.63
TURDA2	TURDA1	70.33	24.68

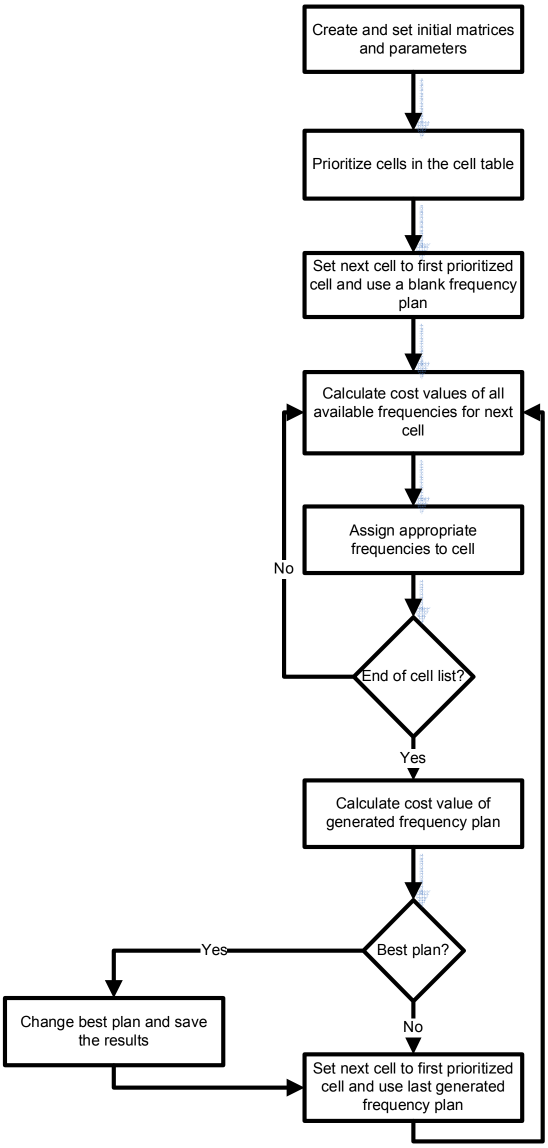
The algorithm of developed program is based on cell prioritizing and cost calculation. A large number of interferer makes is harder to find a frequency for a source cell. Therefore, our program prioritize cells in the cell table according to interferer count in ICDM. If interferer count of cells are equal, this software considers highest busy hour traffic (Table 3). Our application starts from first ordered cell in prioritized table to find frequency.

Table 3: Prioritized cell table

Priority	Cell	Busy hour Traffic (E)	Interferer Count
1	AHMTL2	26.8889	4
2	AKBAL1	9.8557	3
3	AHMTL1	3.8654	3
4	TURDA1	23.3690	2
5	TURDA2	19.5540	2

For each cell in prioritized table, this program calculates cost values of all available frequencies using ICDM table and busy hour traffic data in order. Furthermore, because of the seperation constraints, a cost value of 10000 is assigned for same channel using in co-site and a cost value of 1000 is assigned for adjacent channel using in co-site. To cells one by one, the program assigns frequencies that have lower costs. Cost of a cell is equal to sum of costs of assigned frequencies and cost of a frequency plan is equal to sum of cell costs.

The complete program is intended to work like this:



This program executes an infinite loop. Users can terminate the program and take last saved frequency plan. Furthermore, initially users can set a finite loop for frequency planning. After setting the loop, users should set available carriers to use for frequency planning.

We set available carrier values between 1 and 15 and ran the program with the values in Table 3 and Table 2. After running the program, appropriate carriers were assigned to these cells. The results are shown in Table 4.

Table 4: Results of frequency planning

Cell	Car. 1	Car. 2	Car. 3	Car. 4	Car. 5
AHMTL1	1	3			
AHMTL2	5	7	10	12	14
AKBAL1	5	7	15		
TURDA1	1	3	9	11	13
TURDA2	4	6	8	15	

The cell frequency costs of result plan are shown in Table 5. For example, frequency cost of second carrier (3) of "TURDA1" cell is equal to 1003,65. This cell has two interferers. The first one is "AHMTL2" and the second one is "TURDA2". The value of 1003,65 is calculated with the following processes:

- "AHMTL2" and "TURDA2" interferer cells have not a carrier value of 3. Thus, there is no co-channel interference from these cells.
- "AHMTL2" cell has not a carrier value of 2 or 4. Thus, there is no adjacent channel interference from this cell.
- "TURDA2" cell has a carrier value of 4. Thus, there is adjacent channel interference from this cell. "Adjacent Channel Interfered Traffic(%)" value of this interferer cell is equal to %15,61. "Busy hour Traffic (E)" value of "TURDA1" cell is equal to 23,3690. The product of 0,1561 and 23,3690 is equal to 3,65.
- "TURDA1" and "TURDA2" are co-site cells. Thus, a cost value of 1000 is added to 3,65 because of adjacent channel using in co-site. The sum of 3,65 and 1000 is equal to 1003,65.

Values in Table 5 are recalculated at every step of the loop. In each step, this table is used to assign an appropriate frequency that has lower cost than other frequencies. After each frequency assignment, frequency costs are recalculated for next assignment. A cost value of 100000 is assigned for same and adjacent channel using in same cell. After completion of assignments in same cell, cost value of 100000 is removed from all assigned frequencies and adjacent frequencies of this cell. Furthermore, Table 5 is used for calculation of cell cost values. For example, carrier values of "AKBAL1" cell are 5, 7 and 15. This cell has a cost value of 2,09 (0,55 + 0,55 + 0,99).

Table 5: Frequency costs of cells

Fr	AHMTL1	AHMTL2	AKBAL1	TURDA1	TURDA2
1	**0,10**	10024,76	3,32	**0,00**	10013,8
2	0,00	2023,95	1,91	0,00	2009,65
3	**0,10**	10024,95	3,59	**1003,65**	10013,8
4	1000,56	1013,92	1,95	10010,87	**1005,73**
5	10001,9	**0,48**	**0,55**	2008,55	2,51
6	2001,09	1,95	0,99	10011,17	**1,81**
7	10001,9	**0,48**	**0,55**	2008,55	2,51
8	1000,56	2,78	1,92	10010,87	**1005,73**
9	1000,64	3,27	3,25	**1003,95**	10014,7
10	10001,9	**1,66**	1,87	1,25	2012,16
11	2001,17	3,08	2,98	**0,60**	10015,6
12	10001,9	**1,66**	1,87	1,25	2012,16
13	2001,17	3,08	2,98	**0,60**	10015,6
14	10001,9	**1,02**	1,21	1004,90	1007,33
15	1000,56	2,05	**0,99**	10010,87	**0,91**

Total cost of the result plan is shown in Table 6. Total cost value is equal to sum of cell cost values. This value is used for determining of the best plan. Our program is based on decreasing total cost value.

Table 6: Total cost of generated frequency plan

Cell	Cost Value
AHMTL1	0,20
AHMTL2	5,30
AKBAL1	2,09
TURDA1	2008,80
TURDA2	2014,18
TOTAL	**4030,57**

6. Conclusion

A problem is that the bandwidth and hence the number of frequencies is not unlimited and therefore the same frequencies have to be repeated. The ambition is to do this in such a way that the interference between the signals is as small as possible, and this requires frequency planning.

As the interference level directly affects the speech quality and the amount of dropped calls in the system, the interference level in a radio network has to be kept to a minimum in order to use the limited frequency spectrum in an efficient way.

At this paper, we have developed an application that uses mobile measurments and generates an appropriate frequency plan. These frequencies are assigned to cells which serves to mobile equiments of the subscribers whose are affected by quality of the radio network. Therefore, usage of measurements of mobile equipments is important for frequency planning.

This implementation has been tested at a GSM network operator. Generated frequency plan has been used in cells of this operator in Izmir and Manisa.

7. References

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