ADJACENT CHANNEL INTERFERENCE
Impact on the Capacity of WCDMA/FDD Networks

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Abstract: The adjacent channel interference (ACI) can result in a reduced network capacity in a multioperator WCDMA/FDD environment. This paper is devoted to the study of the ACI, using a static simulator. Simulations were performed in order to identify particular scenarios and network compositions where ACI plays a major role in the system capacity. On the basis of the results, the authors identify the best strategy for frequency deployment within the available spectrum. It is demonstrated that the macro carrier should be located in the centre of the frequency band, protected from the ACI introduced by other operators. It is, in fact, the carrier which suffers the greatest losses caused by the increase in ACI. Furthermore, the micro carrier should be placed as close as possible to the adjacent channel of other operators in order to maximize system capacity.

1 INTRODUCTION

At the moment radio spectrum is becoming increasingly more occupied, making its management a vital tool to network planning. It is under these circumstances that the third generation (3G) mobile communications systems emerged, and in particular the UMTS (Universal Mobile Telecommunications System) in Europe. The air interface chosen for the 3G UMTS system was WCDMA (Wideband Code Division Multiple Access) for the paired bands FDD (Frequency Division Duplex). The scope of this paper is to study the impact of frequency utilization on WCDMA/FDD networks and develop a strategy to optimise it.

The performance of any CDMA system is conditioned by the interference. From the various possible sources of interference that are present in these systems this paper focuses on the study of adjacent channel interference (ACI) and its effect on the overall capacity of the system.

This study consists of five main sections. Following a brief overview of a few features of UMTS related with the options chosen for the simulations, to be found in Section 2, the criteria for the choice of the tested scenarios are explained in Section 3. Section 4 presents the results obtained with the simulated scenarios, and final conclusions are drawn in Section 5.

2 INTERFERENCE ISSUES IN UMTS/FDD NETWORKS

When defining the UMTS system, 3GPP (3^{rd} Generation Partnership Project) inferred that each radio channel has a bandwidth of 5 MHz and the channels allocated are positioned beside each other in uplink and downlink bands separated by 190 MHz (3GPP 25.101). Each channel has its carrier and these are assigned to the UMTS operators in the market.

The strategy designed to reduce the interference, thus achieving the highest possible capacity, consists in identifying optimal spacing between carriers in the radio spectrum available for use. For this purpose, a specific frequency arrangement must be considered, as it may vary from country to country.

The initial licensed spectrum for UMTS in FDD mode was a band with twelve carriers, both uplink and downlink. The case considered includes four operators, each of which has been allocated three carriers. Within the allocated band, it is

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possible to choose the spacing between its carriers and the distance from adjacent operator carriers. 3GPP defines for the spacing between channels a raster of 200 kHz (3GPP 25.104), which means that the spacing between carriers can vary in increments of 200 kHz around 5 MHz.

As seen in Figure 1, in order to decide which spacing should be used, more issues must be taken into account, to prevent the carriers from encroaching on their neighbours. Consequently, bearing in mind the limits typically used in simulations, it has been chosen to vary the distances between the values 4.6 and 5.2 MHz.

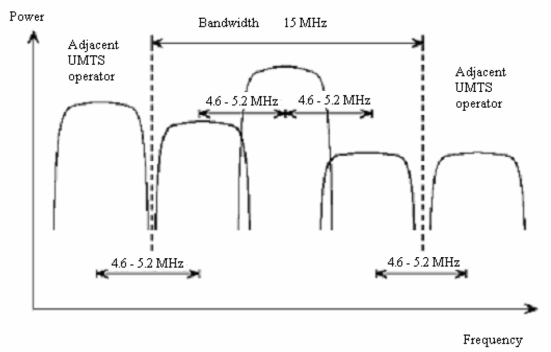

Figure 1: Spacing between carriers in a UMTS system (adapted from (Holma and Toskala, 2002))

In a WCDMA system, developed in the above context, the interference can stem from a large number of sources, namely, thermal noise, traffic in the same cell, traffic in adjacent cells and traffic from operators using adjacent cells.

Possible ways of measuring the interference leakage between connections operating on different carriers must be considered. As the filter is not perfect, when transmitting in its own channel, one carrier will send part of its power into adjacent channels. This effect is measured as the ACLR (Adjacent Channel Leakage Ratio). On the other hand, the receiver filter is unable to receive only the desired signal alone, which is why the rejection of the adjacent channel signal is measured as ACS (Adjacent Channel Selectivity). Moreover, when considering the existence of two carriers which interfering with each other, the total interference is given as an ACIR (Adjacent Channel Interference Ratio) and determined by (1).

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \qquad (1)$$

Furthermore, this source of interference can be seen both from the uplink and from the downlink standpoint. Consider an uplink connection, whose ACIR is given in (2) below. As it is quite likely that the filter in the user equipment (UE) will be poorer than the filter in the base station (BS), the UE ACLR dominates in the case of uplink. In downlink, the situation is analogous, as seen in (3), where the UE ACS dominating on this occasion.

$$ACIR_{UL} = \frac{1}{\frac{1}{ACLR_{UE}} + \frac{1}{ACS_{BS}}} \qquad (2)$$

$$ACIR_{DL} = \frac{1}{\frac{1}{ACLR_{BS}} + \frac{1}{ACS_{UE}}} \qquad (3)$$

One of the essential parameters used in the simulation was that the value of the filter depends on the spacing given to the channels. 3GPP defines the filter's mask, while identifying minimum values for filters at 5 and 10 MHz [3, 4]. However, in this project more realistic values were used, which correspond to real equipment presently available. These values may be found in Table 1.

Table 1: Values of the filters used in BS and UE

Spacing (MHz)	ACLR (dB)		ACS (dB)	
	UE	BS	UE	BS
5	33	60	33	70
10	43	65	43	

When simulations were run using spacing different from 5 or 10 MHz, e.g. 4.6 MHz, a logarithmic regression is made to convert the filter value and obtain a valid method to compare the results.

3 SIMULATION SCENARIOS

The choice of which scenarios to study was not as simple as it might be assumed at first glance. One of the goals in this paper was to find scenarios where ACI has a major role on the network's capacity, in order to understand the impact of placing carriers with different spacing. In (3GPP 25.942), the authors give an idea of the issues to be born in mind when choosing which scenarios to simulate.

In a preliminary stage, the search started with the study of the representative scenarios of rural and urban environments. When simulating two operators, BSs working with adjacent carriers were uniformly distributed over a map. In order to simulate a worst case situation, the sites of both operators are not co-located and the interoperator spatial offset is equal to the cell radius (Hiltunen, 2002).

It was found that the inter-frequency interference impact on the capacity was minimal, when compared with the intra-frequency interference. The reason for this result lies in the fact that there are too many BSs from the same carrier interfering with each other.

The next step taken was to identify scenarios where the ACI played a significant role, at least as important as the interference coming from the connections working on the same carrier. Following simple scenarios, where just a few BSs and two carriers were taken into account, the analysis developed to encompass broader environments simulating urban centres with many antenna sites and three carriers.

A simple map was used as an entrance parameter to the simulator, with no additional information, apart from UE and BS positions. When placing the BSs of two different carriers, one must decide whether they are co-located, i.e. both cells lie on the same site, or not. In the latter situation, it is assumed that the worst case for ACI happens, i.e. the adjacent channel site is located at the coverage edge of the first channel cell.

The simulator used to achieve this analysis was static, using a Monte-Carlo evaluation method. As a result, the users were placed randomly on the map. Following the iterative process, only the connections with sufficient Eb/No (or signal to noise ratio - SNR) for the appointed service were considered to be served by the system. This simulator was adapted from the previous one described in (Laiho et al., 2002) and (Wacker et al., 2001). By examining many static situations, referred to as snapshots, network capacity is estimated through the average number of the served users (Povey et al., 2003).

The bit rates tested in this study were chosen in accordance with the services expected to be offered by operators in the first implementation phase. In this case, 12.2 kbps with CS (Circuit Switching), 64 kbps with CS and, finally, 128 kbps in downlink and 64 kbps in uplink using PS (Packet Switching). The results are presented taking into account users accessing one of these three types of services.

The UE power classes considered for determining the maximum output power were class 3 (24 dBm) for voice and class 4 (21 dBm) for data services (3GPP 25.101). The BS maximum output power used was 43 dBm.

Two types of antennas were chosen to simulate macro and micro BS: for the macro BS, tri-sectorized antennas with 18 dBi of gain, and for the micro BS, omni-directional antennas with 4 dBi of gain.

Two different propagation models were considered to calculate the path loss according to the characteristics of the environment (both for outdoor propagation). For rural scenarios the COST 231 Hata model was used. The main input parameters for the model are the UE antenna heights, 1.5 m, and BS antenna heights, 35 m. For the urban environment the propagation model applied was COST 231 Walfish-Ikegami. The main parameters used are UE antenna heights, 1.5 m, BS antenna heights, between 10 and 25 m (depending if they are macro or micro), street width, 20 m, building separation, 40 m, and building height, 12 m.

4 RESULTS

In the extended study that originated this paper, a wide range of scenarios and environments were considered (Figueiredo and Matos, 2003). Urban, rural and motorway environment were tested using layers containing twenty-three macro cells placed in the form of a grid. Furthermore, eight scenarios with only a few antennas (five at the most) were run to simulate specific situations using macro and micro cells. The dense urban environment was simulated, by using macro cells layers and micro cells to cover identified hotspots. In this paper, only the three most significant tests will be presented.

At the end of each simulation, the outputs were analysed. Apart from the maps indicating the BS and UE position, the network's capacity (measured in average number of served users) and the capacity loss (when compared with no ACI), parameters like the ratio between sources of interference were also analysed in (Figueiredo and Matos, 2003). The interference sources considered in the results included the interference coming from the adjacent channel, the interference from the same channel from neighbouring cells and the interference from the same cell (due to the other users connected to the same BS).

A maximum load of 50 % was allowed in the radio interface.

4.1 Case 1: Small scale networks with two operators

This scenario was developed to study the impact of a new micro BS placed by an operator to cover a hotspot in the middle of an existing network of macro BSs from the adjacent carrier competitor.

The users from both operators have been located around the centre of the area considered. The area simulated has a high density of active clients, as shown in Figure 2.

The number of users presented in Figure 2 corresponds to the initial users from each operator, and are placed on the map at the simulation start.

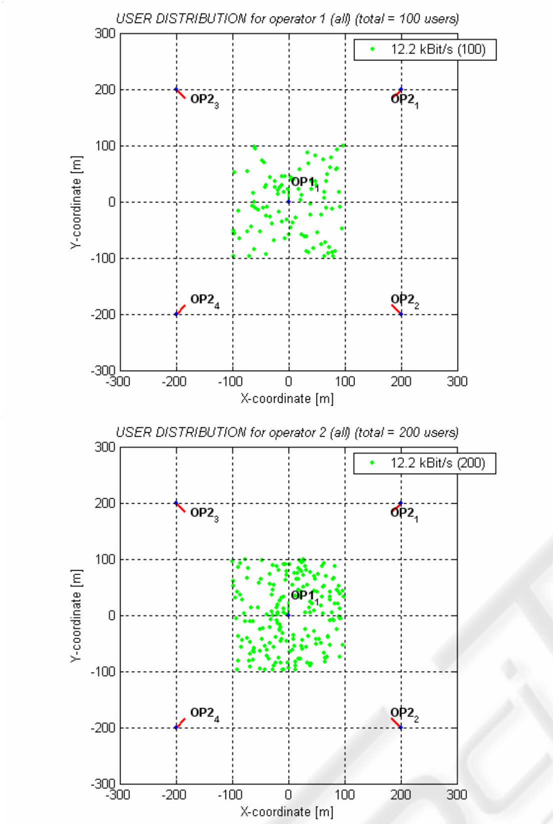

Figure 2: Location of UE (CS 12.2) and BS (Case 1)

Table 2 shows the average number of users served employing different channel spacing and the percentage of loss compared to the case where no adjacent operator exists (without ACI) for the CS 12.2 kbps service.

It has been verified that the operator 2, covering the area with four macro BSs, is the one that suffers most from interference. This may be explained by the fact that users of operator 1 (micro BS) are closer to the antenna, which therefore makes it more difficult for them to lose the connection. A comparison of the results obtained from the simulations performed with the three services tested for operator 2, is shown in the graph presented in Figure 3.

Table 2: Results from the simulated scenario (Case 1)

CS 12.2 kbps	Capacity (average number of users)	Capacity Loss (%)
Operator 1		
Without ACI	77	0
4.6 MHz	76.1	1.17
4.8 MHz	75.8	1.56
5.0 MHz	76.7	0.39
5.2 MHz	76.7	0.39
10.0 MHz	77	0
Operator 2		
Without ACI	162.1	0
4.6 MHz	44.8	72.36
4.8 MHz	104.7	35.41
5.0 MHz	126.2	22.15
5.2 MHz	134.6	16.96
10.0 MHz	155.5	4.07

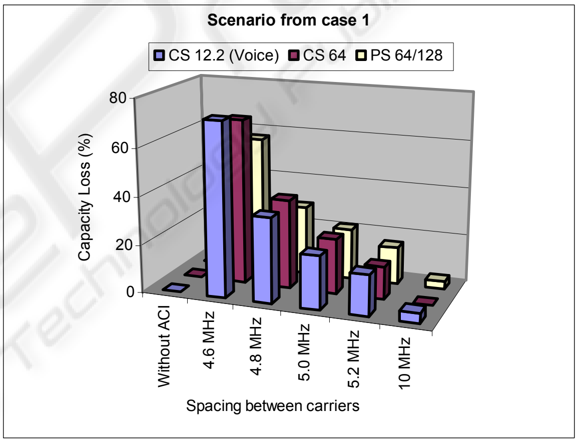

Figure 3: Capacity Loss of operator 2 (Case 1)

4.2 Case 2: One layer macro and two layers micro

In the situation shown in Figure 5 several macro BSs were placed to form a grid and cover the area to serve users of operator 1. Four hotspot areas (with higher user density) from both operators 1 and 2 were placed and micro BSs located to cover them.

In this case, it has been tested an environment where three carriers coexist and interfere with each other. Operator 1 has one carrier for macro BSs (f1) and another for micro BSs (f2). Operator 2 has only one carrier for micro BSs (f3). The three channels were allocated next to each other in the radio spectrum as shown in Table 3.

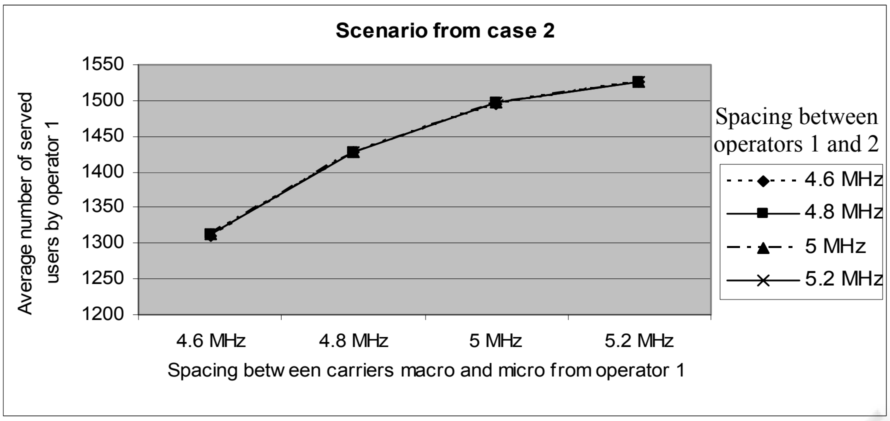

Figure 4: Capacity of operator 1 (Case 2)

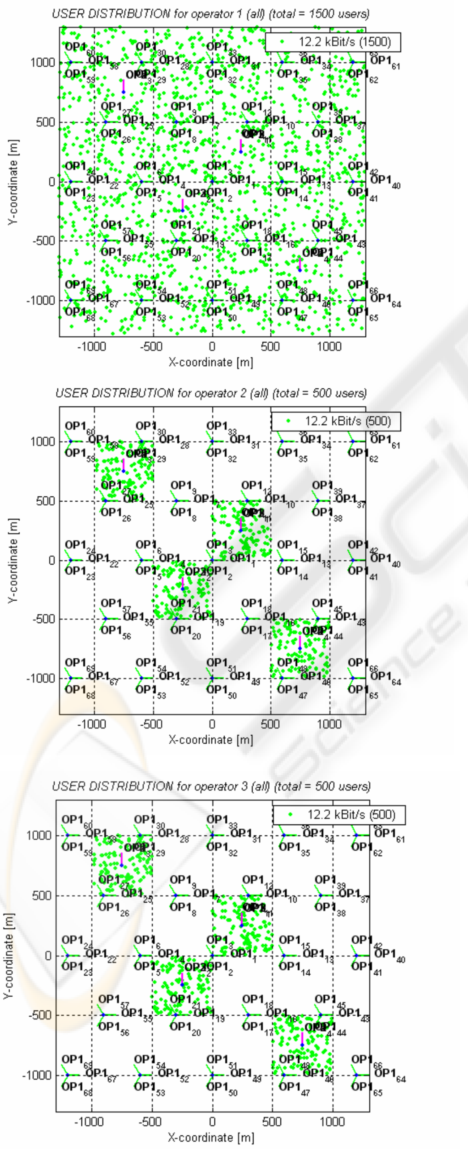

Figure 5: Location of UE (CS 12.2) and BS (Case 2)

Table 3: Frequency planning with macro (M) and micro (m) networks (Case 2)

Operator 1		Operator 2
f1 (M)	f2 (m)	f3 (m)

Once again the spacing considered between each of the three channels varied within the range 4.6 to 5.2 MHz.

The results obtained from these simulations are given in Figure 4. The graph shows the average number of users served by operator 1, and take into account both the users connected to the macro (f1) and to the micro (f2) layers. As expected, it can be seen that the network capacity rises when the spacing between f1 and f2 widens. As both micro layers accommodate fewer users than the macro layer from operator 1, it is evident that the distance between micro layers (f2 and f3) from the different operators does not have a great impact on the capacity of operator 1. This fact is confirmed by the graph, since the lines are almost overlapped.

Following the analysis of these results, it is logically preferable to choose a wider spacing between carriers f1 and f2, in order to achieve an increase in the capacity of operator 1. At the same time, it is reasonable to leave the lowest distance to the carrier from operator 2 (f3), since the damage is imperceptible, towards optimisation of the spectrum allocated.

4.3 Case 3: Two layers macro and one layer micro

As in the previous case, in Case 3, the authors tested the impact of interference among three carriers controlled by two operators. However, in this case, there are two major macro BSs grids from operators 1 and 2. The same hotspots mentioned in

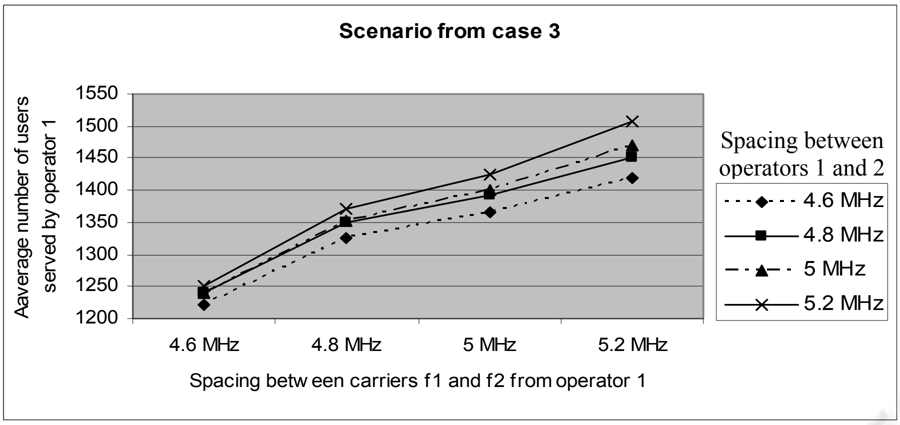

Figure 6: Capacity of operator 1 (Case 3)

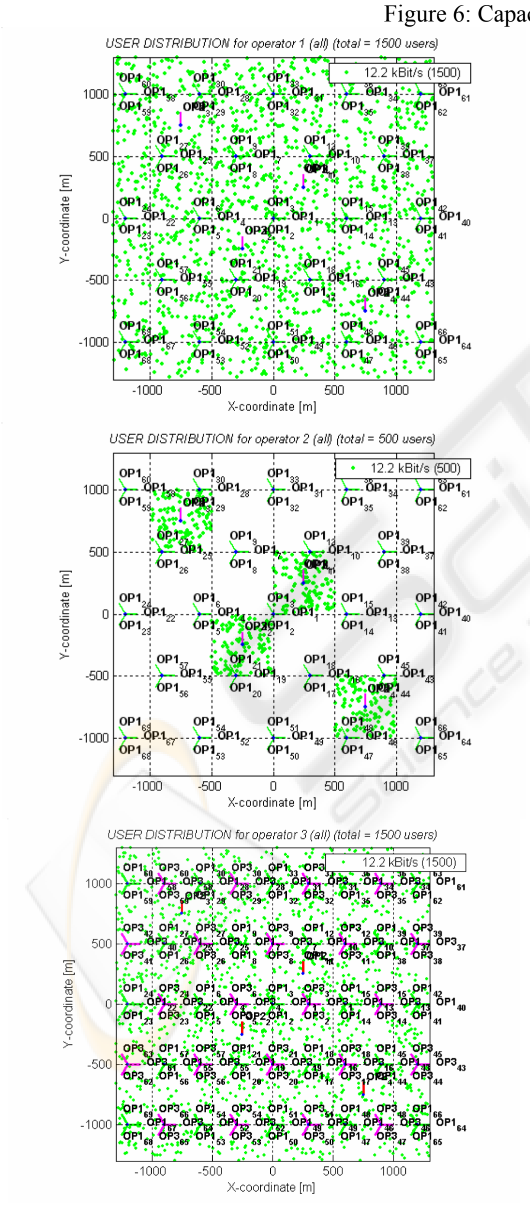

Figure 7: Location of UE (CS 12.2) and BS (Case 3)

Case 2 are now covered with micro BSs by operator 1 only, as seen in Figure 7. Thus, the configuration of the radio spectrum is similar, the only difference being that there are two channels for macro BSs and one for micro BSs, as shown in Table 4.

Table 4: Frequency planning with macro (M) and micro (m) networks (Case 3)

Operator 1		Operator 2
f1 (M)	f2 (m)	f3 (M)

The results, presented in the graph from Figure 6, were obtained by using the same procedure followed in Case 2.

As before, the network's capacity grows as the distance between f1 and f2 becomes larger. However, it can now be confirmed that the spacing between the two adjacent carriers from different operators (f2 and f3) has a significant impact on the overall capacity of operator 1. This feature is due to the fact that carrier f3, from operator 2, now accommodates a much larger number of users in its macro layer.

In this situation the analysis has to be considered more carefully than in the previous case. To achieve maximum capacity in operator 1, apparently the best solution would be to choose the maximum spacing between carriers f1 and f2 whilst, at the same time, also leaving the highest distance to the adjacent operator channel (f3). However, in doing so, one is failing to take into account the fact that each operator has three allocated channels. Note that, in the future, it will be valuable to use all of them to face an anticipated traffic increase. As a result, it would wise to choose a configuration in which the two carriers from operator 1 are not positioned in such a way that they occupy the free space left by hitherto unused third channel.

5 CONCLUSIONS

In this paper the authors studied the impact of the ACI on a general network's capacity. This led to some more useful conclusions that may be applied when planning the launch of a WCDMA/FDD radio networks.

When considering two wide BSs grids that lie close to each other to cover a specific area, it was observed that the main interference source is not the ACI, but interference from the neighbouring BSs, working on the same channel.

From scenarios like the one presented in Case 1, it was noted that the macro BSs are more likely to suffer from ACI when new hotspots are covered with micro BS by a competitor operator. This fact is explained by the longer distance between the user and the macro BS, as compared with the latter. As the macro carrier may suffer a greater impact on capacity, it should be protected and placed in the centre channel of the allocated spectrum. This choice is irrespective of the number or type of carriers used, assuming that the operator launching a service uses at least one macro carrier.

It may also be seen, from these small and specific case scenarios like Case 1, that the use of a 4.6 MHz spacing may cause critical problems, leading to a serious reduction in the network's capacity. Therefore, distances between carriers of 4.6 MHz or less should never be used. Although in the vast majority of the situations the loss may not be that disastrous, the possibility of having certain areas with losses above 50 % is unsustainable to an operator.

Upon considering an available spectrum of three carriers, and assuming that the macro carrier is located in the centre channel, it is intended to decide where to place the micro channel. From Case 2, where operator 2 placed a micro carrier in the channel adjacent to the spectrum of operator 1, it was seen that the distance between the two channels was almost irrelevant to the overall network's capacity. However, when operator 2 has a macro carrier on the channel, adjacent to operator 1, the latter suffers the consequences of a reduction in the distance between different operators' channels. On the basis of the compromise solution of not occupying the spectrum of the three channels allocated using two carriers only, it may be concluded that a spacing of 5.2 MHz between f1 and f2 and 4.8 MHz between f2 and f3 is the best option.

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