Impact of tradeoff between blocking and interference on TDMA cell capacity planning

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Abstract: Cell capacity planning is a key phase of the expansion of cellular networks. The growth of communications demand requires improving the capacity of the networks regularly. However, cell capacity planning is difficult to achieve while it must take into account two conflicting objectives: minimising the blocking rate and reducing the interference. In TDMA systems, current literature offers few studies dealing simultaneously with both criteria. In this paper, we propose a bicriteria model for TDMA cell capacity planning as answer to a flexible management of the tradeoff between blocking and interference phenomena. While cell capacity dimensioning requires the offered traffic load on each station, we also present a module for offered traffic computation where user retrials and redials are considered. At the end, we carry out tests on two real world datasets with different network architectures and traffic loads in order to assess the efficiency of the approach.

Keywords: cellular networks; cell capacity planning; traffic loss; multicriteria optimisation.

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1 Introduction

To meet the increase of traffic load, whatever voice or data connections, mobile network operators need to improve the traffic capacity of their networks. At cellular level, it involves to raise the number of radio channels per cell. However, the interference limitation of cellular systems does not enable the reuse of frequency channels below a minimum distance between cells (Lee, 1998). Then, radio cells are aggregated into clusters forbidding the reuse of frequency channels inside them. The total available frequency channels of the system limit the number of radio channels per cell.

Nevertheless, several solutions more or less expensive are available to get this traffic expansion challenge. We are not considering here the more expensive one, which is the introduction of new cellular layer, like UMTS, on existing one, like GSM; this multilayer approach is service-driven oriented while the main objective is to get higher throughput with a new technology. Inside a cell layer, the classical procedure to load a higher level of user density is to reduce the cell size (Walke, 2002). It can be achieved with site densification, i.e. adding new sites between existing sites, and site sectorisation, i.e. replacing omnidirectional antenna by sectorised antennas on existing site. When these options are already used, as this is the case for the higher-density TDMA networks in big cities, we come back to the interference limitation problem: we like to add radio channels per sector but we do not want to exceed the carrier-to-interference (C/I) ratio. This is the topic of this paper: we are considering as a whole the tradeoff between the capacity expansion inside a system through the increase of the number of radio channels per cell, and the Grade of Service (GoS), the system is able to provide when interference are growing up. Our work is bringing new solution in the dimensioning step of the capacity by providing a bicriteria procedure to study simultaneously the capacity and the interference requirements.

Let explain the way we currently manage this duality by separating capacity and interference evaluation. The radio channels dimensioning are theoretically computed from the traffic demand and the maximum percentage of calls the operator accepts to be blocked by the system. This percentage is known as call blocking rate and is often used as criteria for performance comparison (Katzela and Naghshineh, 1996). A priori determining the optimal blocking rate for a given network is difficult. On one hand, the mobile operator wants to raise the number of radio channels on each cell until the system limits are reached in order to reduce the blocking rate, and therefore to increase the cell capacity. On the other hand, improving the traffic load supported by the network leads to an intensive reuse of radio-frequency channels and consequently pushes up interference. Applying a theoretical dimensioning on a real, i.e. nonhexagonal cells, and heavy load network without considering the interference level of this network allows the operator to get a fair capacity solution rapidly but does not allow the operator to get the best performance of the cellular system. It needs to break the rules that separate the computation of interference of the specific network and the blocking rate values used for dimensioning.

This discussion leads to a bicriteria formulation of the cell capacity planning problem. We take into account two antagonistic criteria: minimising the call blocking by adding radio channels and minimising interference linked to additional spectrum reuse. To deal with this problem, a technique inspired by the epsilon-constraint method for multicriteria optimisation problems is proposed (Hu et al., 2003). The goal is to search and compare several configurations of network for cell capacity planning. Each configuration represents a particular tradeoff between traffic loss due to call blocking rate and traffic loss caused by interference.

Two main sections organise this paper: Section 2 is an introduction to different concepts while Section 3 describes the work done and the results. The study is based on GSM system as it is the main worldwide system, and practical experiments will use traffic loads and cells configurations from two real networks. In Section 2, we introduce the problem components through the notions of call blocking, call-redial and call-retrial and the interference modelling. In Section 3, we underline a description of our work on cell capacity planning with three subsections. Section 3.1 reviews previous algorithmic works done on this subject and comments the results of these studies. Section 3.2 details the optimisation procedure we proposed to tackle the problem of optimising traffic loss linked to call blocking rate and interference. Two modules are involved in this part: the first module to extract the traffic demand used as input of the other module, and the second module for the computation of cell capacity based on bicriteria optimisation. The last subsection shows the experimental results carry out on real-world *data*[1] in order to assess the quality of the cell capacity planning method. Conclusions and future works are given in Section 4.

2 Definitions on traffic load and interference

2.1 Call blocking rate

2.1.1 Traffic channel

A GSM network (Lee, 1992) is composed of a set of sites that locate from one to three base stations (BS). Each BS provides a supply area called a cell that is the area from which a mobile station (MS) is in radio contact with the BS. The size of the cell is adapted to the user density on its specific radio coverage area. Mobile users access the network using radio channels on a time division multiple access (TDMA) basis; eight physical slots or time-division channels divide a carrier frequency. We distinguish two kinds of transmission channels: control channels, used for system control and signaling tasks, and traffic channels, used to carry all user information (speech, data SMS, etc.). Consequently, the number of available traffic channels on one station, defined by c, is deduced from the following equation:

$$c = \text{no. of TRXs} \times 8 - \text{no. of control channels} \quad (1)$$

where TRX defines a transceiver in charge of a carrier frequency. Typically, according to the number of TRXs put on one station, a given number of transmission channels are assigned to signalling and control tasks. Table 1 gives the correspondence between the number of TRXs sets on one station and the number of available traffic channels.

Table 1 The number of traffic channels according to the number of TRXs

Number of TRXs	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Number of traffic channels	7	14	22	29	36	44	51	59

It is clear that the number of available traffic channels limits the number of communications simultaneously carried by one station. Once these channels are occupied, all new calls are blocked and rejected by the system. The station will only be able to accept new communications after the release of at least one traffic channel.

2.1.2 Traffic model

Owing to temporal fluctuations of traffic, the offered traffic at the busiest hour on each station generally estimates the call blocking rate. We define T_i^{offered} as the offered traffic on the station S_i measured in *Erlang*. T_i^{offered} represents a statistical measurement of traffic corresponding to the average number of simultaneous calls during the busiest hour. It includes the carried traffic and the lost traffic by the system as mentioned in Walke (2002). In the field of traffic engineering, we model the voice traffic evolution by a Poisson law (Grillo et al., 1998; Jabbari and Fuhrmann, 1997; Tunnicliffe et al., 1998). In Tunnicliffe et al. (1998), we present an indepth study on the relevance of Poisson modelling of traffic; this model is usually called *Erlang B* model.

In *Erlang B* model, the inter-arrival delay between fresh calls as well as the channel holding time are assumed to be exponentially distributed with a respective mean of $1/\lambda_i$ and μ_i (measured in hours). Knowing that the mean duration between the arrivals of two consecutive fresh calls on the station S_i is $1/\lambda_i$, we deduce that the average number of fresh calls per hour is λ_i. Knowing that the average call duration is μ_i, the offered traffic on the station S_i is calculated as

$$T_i^{\text{offered}} = \mu_i \times \lambda_i \tag{2}$$

2.1.3 Call blocking rate

From the model described above, we compute the call blocking rate on one station in two ways. The first way consists in simulating the call arrival process into the system. The second method uses the analytical formulation of call blocking rate described by the *Erlang B* formula given by the following equation:

$$\beta(c) = \frac{1}{1 + \sum_{i=1}^{c} \left(\frac{c}{T^{\text{offered}}} \right) \left(\frac{c-1}{T^{\text{offered}}} \right) L \left(\frac{c-i+1}{T^{\text{offered}}} \right)} \tag{3}$$

where *c* is the number of available traffic channels on the station.

2.2 Call retrial and redial

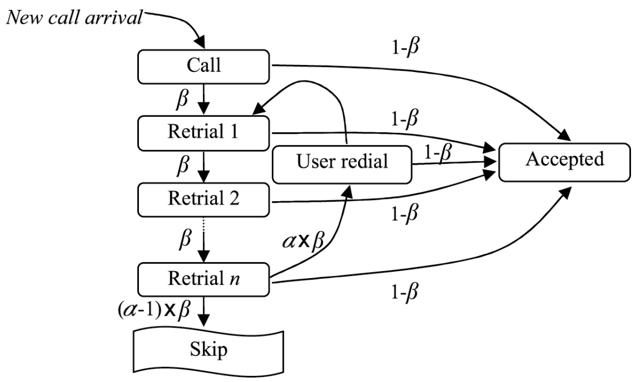
The call blocking rate β_i on the station S_i hardly depends on the estimation of the offered traffic as Equation (3) shows. However, the amount of offered traffic on operational networks is not directly captured by the Operations and Maintenance Center (OMC). Call failures involve automatic recalls on behalf of the system (retrial) and manual recalls on behalf of the users (redial) (Marsan et al., 2001). Then, data collected by the OMC are the aggregation of the accepted new requests Na_i and the accepted recalls Ra_i as carried traffic, and the aggregation of the blocked new requests Nb_i and the blocked recalls Rb_i as lost traffic. As well, the statistical model presented in Section 2.2 is based on interdependence assumption between call requests, so we need to compute the number of new call attempts from OMC information. We define a_i for carried traffic (number of accepted calls and recalls) and b_i for lost traffic (number of blocked calls and recalls) from the number of calls and recalls as follows:

$$a_i = Na_i + Ra_i \tag{4}$$

$$b_i = Nb_i + Rb_i \tag{5}$$

Onur et al. (2000, 2002) propose an analytical model that computes the number of new call requests ($Na_i + Nb_i$) by using the number of accepted calls a_i and the number of blocked calls b_i captured by the system. The advantage of an analytical estimation of offered traffic is that the computation is very fast in comparison with the simulation method. In this analytical model, when a call blocking occurs with a probability β, a succession of automatic recalls is launched. These retrials stop either when the communication is accepted or when it reaches the maximum number of automatic recalls, defined by *n*. If the call fails, the user may then decide to redial the call with a probability α. Figure 1 depicts the setup process of a new call in the system.

Figure 1 Retrial and redial analytical process (Onur et al. 2000, 2002)



The value β refers to the observed blocking rate on the station *S*. We extend this notation to the blocking rate β_i for the station S_i. The ratio between the number of blocked requests and the total number of requests is

$$\beta_i = \frac{b_i}{a_i + b_i} \quad (6)$$

According to this model, the average number of retrials and redials per original new call is

$$Nr_i = \sum_{j}^{\infty} \left(\begin{array}{l} \sum_{k=0}^{n-1} (j(n+1)+k)\beta_i^{(jn+k)}(1-\beta_i) \\ +((j+1)n+j)\beta_i^{(j+1)n}(1-\beta_i) \end{array} \right) (\alpha\beta_i)^j$$
$$= \frac{\alpha\beta_i^{n+1}}{1-\alpha\beta_i^{n+1}} + \frac{\beta_i(1-\beta_i^n)}{(1-\beta_i)(1-\alpha\beta_i^{n+1})} \quad (7)$$

where n is the maximal number of automatic recalls. To get the number of effective new calls, it is sufficient to assume that the sum of recorded requests (blocked and accepted) is the result of the original requests and their recalls, that is:

$$(Na_i + Nb_i) \times (Nr_i + 1) = a_i + b_i$$

From this formula, we conclude that the number of fresh calls is

$$N_i = Na_i + Nb_i = \frac{a_i + b_i}{Nr_i + 1} \quad (8)$$

To compute the offered traffic on one station S_i, it is necessary to get an estimation of the average channel holding time μ_i. This is done by dividing the carried traffic, T_i^{carried}, by the number of carried calls, a_i Equation (9). Then, the offered traffic is got from the product of the channel holding time (in hours) by the number of new calls Equation (10):

$$\mu_i = \frac{T_i^{\text{carried}}}{a_i} \quad (9)$$

$$T_i^{\text{offered}} = \mu_i \times N_i \quad (10)$$

2.3 *Interference modelling*

2.3.1 *Interference and traffic loss*

A cell is the area covered by one station. The cells are overlapping each others and inside these overlapping zones the mobiles receive several signals coming from the different stations. Interference between the signals occurs when these signals are carried by the same frequency channel (cochannel interference) or close frequency channels on the spectrum (adjacent-channel interference). Thus, the amount of interference not only depends on the network hardware configuration, i.e. the transceivers number, but also on radio resources management. Then, the real estimation of interference and lost traffic from a given hardware configuration of the network cannot be done without taking into account the assigned frequency channels.

Let analyse the impact of frequency channels interference on communications and traffic loss. Problems are due to frequency assignment failure in managing cochannel and adjacent-channel interference when the offered traffic requires a lot of channels. It involves a deterioration of communications quality while the traffic load increases, up to communications interruption when the C/I ratio exceeds a given threshold. The call blocking rate computation explained in the previous section does not take into account this additional traffic loss. Nevertheless, as call blocked, it hardly affects the Quality of Service (QoS) perceived by the subscribers and we must manage it.

Hence, the cell capacity planning challenge is not only a call blocking rate matter, but also improving the call blocking rate needs for additional theoritical channels, which requires higher spectrum reuse rate; then, this higher reuse produces more interference and finally decreases the expected QoS. The challenge is to achieve the best tradeoff between network capacity increasing and communications quality improvement. Up to now, the cell capacity planning procedure does not consider this tradeoff as the network capacity is firstly defined, and the communications quality is a result computed in a second and independent step with the assigned frequency channels. The global optimisation of these two steps to find the best tradeoff is the matter of this paper. Before presenting the proposed method, we introduce below the interference estimation we use.

2.3.2 *Estimated interference*

A set of frequency is assigned to each station of the network according to its number of TRXs and hopping features (Dornstetter and Verhulst, 1987), i.e. the set is equal to the number of TRXs for nonhopping and base-band hopping stations and is larger for synthetised hopping stations. These frequencies will carry the communications on the station's cell.

The objective of the frequency assignment is to find the best distribution, called frequency plan, of the available frequency channels on stations in order to minimise the traffic loss from interference. A lot of works have been done on this matter (Eisenblatter, 2001; Hurly et al., 2000; Lee, 1998; Sarkola, 1997). The coverage loss from interference, i.e. the percentage of cover for which the signal-to-interference ratio is below a given threshold, is often used instead of the traffic loss. If any carrier is scrambled on a pixel of the network coverage, the pixel surface is summed to a lost coverage counter. When the traffic loss is used as criteria, it includes the probability for the carrier to be scrambled or not depending on traffic load of carrier and scrambling stations (Chambreuil and Renaud, 2002).

For our work, we define the following notation: $f_{i,k}$ is the kth frequency assigned to the station S_i and $I(S_i, S_j, f_{i,k}, f_{j,p})$ is the interference estimation, when the frequency $f_{j,p}$ of S_i scrambles the carrier $f_{i,k}$ of S_i. In addition to these input parameters, the function $I(S_i, S_j, f_{i,k}, f_{j,p})$ classically used in frequency assignment problems depends on the overlapping between stations, their respective traffic load and their number of TRXs. We considered a base-band hopping network for which the frame erasure rate (FER) estimate the level of interference on pixels. Then, the traffic loss is computed from a given FER rate at 2%, the most constraining one, 4 and 7%, the low constraining rate. We choose the base-band technology according to its good features under high loads (Chambreuil and Renaud, 2002). In this case, when capacity planning adds TRXs on stations it leads to reduce the collision probability between the frequencies $f_{i,k}$ and $f_{j,p}$.

Hence, the objective function F to minimise is as follows:

$$F = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sum_{k=1}^{nb\text{TRX}_i} \sum_{p=1}^{nb\text{TRX}_j} I(S_i, S_j, f_{i,k}, f_{j,p}) \qquad (11)$$

where, N is the number of stations, $f_{i,k}$ is the kth frequency of the station S_i and $nbTRX_i$ is the number of TRXs of S_i. Note, the relationship between the number of TRXs and the function F: when the number of TRXs increases, the value of $I(S_i, S_j, f_{i,k}, f_{j,p})$ decreases according to a lower collision probability between frequencies. In contrast, the larger the number of TRXs is, the larger is the number of components to sum then it increases the value of F.

3 Cell capacity planning under interference constraints

3.1 Previous works

In the field of cell capacity planning for TDMA systems, few studies take into account the interference load side. Therefore, they rarely address the optimisation of the tradeoff between blocking rate and estimated interference while the traffic load is exponentially growing in the current networks. It is obviously not the case for CDMA systems as IS95 or UMTS as the capacity planning is directly computed with the traffic and interference loads of the stations (Akl and Parvez, 2004; Holma et al., 2000).

Currently, a blocking threshold q is fixed for all stations of the network (Aardal et al., 2001; Lee, 1992; Tunnicliffe et al., 1998). Then, the designer defines c_i, the number of traffic channels of the station S_i in response to T_i^{offered}, the offered traffic on S_i, by calculating the smallest value of c_i that satisfies the following condition:

$$\beta(c_i) < q$$

knowing the necessary number of traffic channels, the number of TRXs on each station is deducted from Table 1.

Among the studies that try to simultaneously deal with the two objectives (interference and blocking), we used two works as reference: Horng et al. (2001) and Matsui et al. (2002). Horng and coworkers proposed a frequency planning model integrating blocking and interference criteria. They globally managed frequency planning and cell capacity planning by aggregating both criteria within a single objective function. The computation of blocking rate on each cell uses the model described in Sections 2.2 and 2.3, whereas the model of interference is a frequency channel separation matrix defining the minimal frequency channel distance to satisfy per couple of stations. This model constitutes a good step towards an efficient procedure for cell capacity planning from interference and blocking criteria. Nevertheless, the model proposed by Horng and coworkers has some inconvenients. At first, the influence of the TRXs number over interference damage does not appear in the separation matrix. Then, simultaneous resolution of cell capacity planning and frequency planning is very complicated from a combinatorial point of view. Finally, the nature of desired tradeoff between blocking and interference is specified before optimisation using the aggregation of both criteria within a weighted objective function. The resolution approach using this aggregated function only gives one final solution while several tradeoff solutions exist. This approach masks the multicriteria features of the problem.

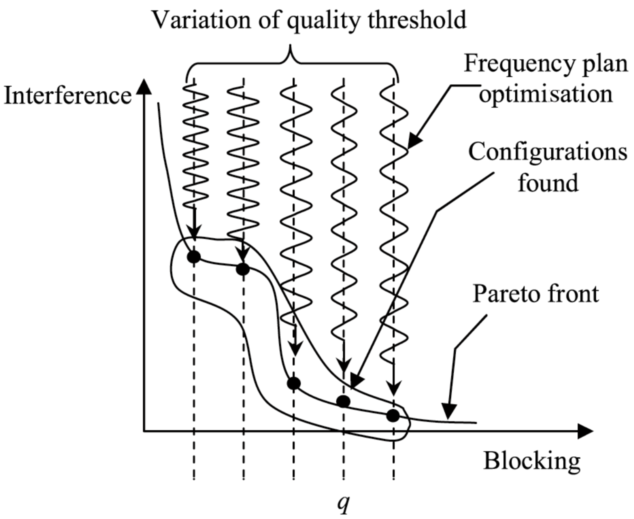
To reduce the combinatorial complexity of the problem, Matsui et al. proposed to solve the problem in two steps (Matsui et al., 2002). A first step aims at determining the greatest number of traffic channels on each station which minimises an aggregative function of blocking rate and costation interference, which is the separation required between frequency channels inside each station. The frequencies are assigned in a second step considering the compatibility constraints between stations. Despite of a better control of the combinatorial complexity of the problem, this approach favours the reduction of blocking rate against interference. Moreover, in the approach the cosite interference, that is, the separation requirements between frequency channels from directive stations located on the same site, is not considered.

3.2 Epsilon-constraint optimisation technique

3.2.1 Method principle

The method we propose for cell capacity planning meets the needs to optimise the tradeoff between blocking and interference in a more flexible and efficient way. The multicriteria optimisation technique called *Epsilon-constraint* inspires the suggested method. The relative simplicity and effectiveness of *Epsilon-constraint* makes it popular among optimisation community (Coello, 1999; Loughlin and Ranjithan, 1997; Quagliarella and Vicini, 1995). The idea is to minimise one criterion (interference in our case) and to maintain the other criterion (blocking rate) under a given quality threshold q. The variation of the quality threshold allows us to generate several configurations on the Pareto front (Coello, 1999) (see Figure 2), that is the solutions that are not worse than any other one on all criteria (*non-dominated solutions*). Each configuration represents a particular tradeoff between the two considered criteria. Among this set of configurations, the final choice lies with the decision maker.

Figure 2 Epsilon-constraint technique for bicriteria optimisation



One of the main advantages of the *Epsilon-constraint* technique is its intrinsic parallel feature when several machines or processors are available. The frequency planning associated to each hardware configuration are independent tasks. Consequently, tasks corresponding to the computation of hardware configuration and frequency assignment can be run in parallel for each blocking threshold as shown in Figure 2. In addition, *Epsilon-constraint* method does not lay down any condition concerning the nature of the Pareto front, convex or concave.

Using this bicriteria method, we tackle both major problems evocated in the previous works. Firstly, the objective function is not an aggregation of blocking rate and interference, which needs to predefine an uncertain aggregative combination, and then limit the features of the problem's solutions tradeoff. Secondly, the combinatory is limited while we do not consider in the same procedure decision variables for blocking rate and frequency assignment problems.

In the further sections, we describe main modules of the algorithm for the computation of offered traffic (*traffic* module) and the computation of cell capacity (*capacity* module).

3.2.2 Offered traffic computation

This module implements the analytical model suggested in Section 2.2 (Equation 10). The objective is to provide an estimation of the offered traffic on each station from data collected by the OMC. We summarise the statistical data contained in OMC to three categories:

- The number of accepted calls on each station a_i
- The number of blocked calls on each station b_i
- The traffic load carried by each station T_i^{carried} in *Erlang*.

We did the computation of offered traffic on each station according to the following steps:

1. Computation of the observed blocking rate β_i according to formula (6)
2. Computation of the recall rate Nr_i according to formula (7)
3. Computation of the number of new calls N_i according to formula (8)
4. Computation of the average channel holding time μ_i according to formula (9)
5. Computation of the offered traffic T_i^{offered} according to formula (10).

3.2.3 Cell capacity computation

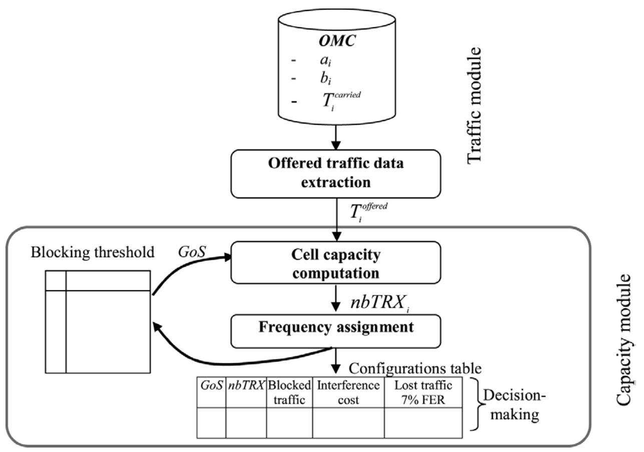
The previous module computed the offered traffic per station. Let $Q = \{q_1, q_2, ..., q_p\}$ be a set of p blocking thresholds. For each value q_s, the number of required traffic channels per station is computed in order to satisfy the blocking threshold, that is the smallest value c_i which satisfies the following condition:

$$\beta(c_i) < q_s$$

From the number of traffic channels c_i, the number of TRXs, $nb\text{TRX}_i$, is got from Table 1 then the frequency assignment step is scheduled. The purpose of this step is to assign the $f_{i,k}$ minimising the function F described by Equation (11). A review of optimisation algorithms for frequency assignment is given by Hurly et al. (2000) and Sarkola (1997). Hybridisation of genetic algorithm and tabu search constitutes the basis of the technique used in this work. The paper (Mabed et al., 2002) details our algorithm. The result of each optimisation phase is one frequency plan.

We run this process from a discrete set of blocking thresholds producing a set of frequency plans with distinct cells capacity and levels of interference. In Figure 3, we summarise the working scheme of the two modules.

Figure 3 Working scheme of cell capacity planning algorithm



3.3 Experimental results

The experimentations reported in this section relate to the validation of both modules, offered traffic computation and cell capacity computation.

3.3.1 Validation of traffic module

In order to validate the offered traffic computation module based on the retrial and redial analytical process, a comparison is done with the offered traffic estimated from the complete simulator given in Figure 1 applied to a single cell. The idea is to simulate the events occurring on one cell such as call arrival, call blocking, retrial and redial mechanisms, up to call processing or aborting. The simulated offered traffic (carried and lost), $T^{\text{simulated}}$, is the result of the simulation phase. However, data related to the number of accepted, a_i, and blocked, b_i, calls attempts (original or not), and the carried traffic, T^{carried}, are collected and stored by the simulator. Then, the goal of the validation process is to compare the offered traffic computed by the analytical model, $T^{\text{analytical}}$, from T^{carried}, a_i and b_i, to the offered traffic got by the simulator, $T^{\text{simulated}}$.

Table 2 provides a comparison between simulated and analytical offered traffics. This comparison is carried out for various values of λ (in seconds) and for four hardware configurations (14, 22, 44 and 51 traffic channels). For each simulation, we write data recorded by the simulator: the offered traffic $T^{\text{simulated}}$, the carried traffic T^{carried} and the number of accepted and blocked attempts. The last column, $T^{\text{analytical}}$, is the offered traffic computed by the analytical model. For retrial and redial parameters, we used the following values: $\alpha = 0.75$ and $n = 4$.

Table 2 Comparison between simulated and analytical offered traffics

1/λ (s)	$T^{\text{simulated}}$ *(Erl)*	T^{carried} *(Erl)*	*Accepted* (a_i)	*Blocked* (b_i)	$T^{\text{analytical}}$ *(Erl)*
		14 TCH			
5	15.52	12.49	502	2930	15.08
6	14.67	12.36	498	1946	13.82
7	11.87	11.23	435	702	11.50
8	11.32	10.90	427	520	11.05
		22 TCH			
3	29.37	21.27	900	6837	27.48
4	19.93	18.37	790	1230	18.79
5	17.48	17.10	720	267	17.20
6	13.98	13.93	570	26	13.93
		44 TCH			
1	78.63	42.56	1760	27,875	72.27
1.2	72.92	42.32	1649	23,045	67.95
1.5	55.94	41.65	1757	11,263	51.43
2	40.84	38.15	1608	2170	38.79
		51 TCH			
1	79.33	50.29	2061	23,092	73.86
1.2	68.41	50.08	2101	14,043	62.50
1.5	55.82	48.43	1931	6165	52.60
2	44.46	42.87	1704	488	42.88

Table 2 shows that the analytical model computes good estimations of offered traffic. Indeed, $T^{\text{simulated}}$ and $T^{\text{analytical}}$ are very close in the considered tests. This estimation is more accurate for low blocking rates, i.e. highest 1/λ, which is a positive result while cell capacity replanning is launched as soon as the blocking rates overtake the threshold (usually around 2%).

3.3.2 Validation of capacity module

The purpose of this section is to show the diversity of network hardware configurations, we got from the tradeoffs between capacity and interference provided by the module of *cell capacity computation*, and therefore to discuss the interest of the method we exposed. To be interpretable we need several tests. We carried out tests on two real-world networks of different sizes and cells distribution. The first network, *B_381*, is composed of 381 stations. The estimation of offered traffic on the whole network is 3367.74 *Erlang*. The second network, *BM_120*, is composed of 120 stations and 364.42 *Erlang* of offered traffic. The available spectrum for both frequency assignments is 62 channels.

Tables 3 and 4 display the characteristics of the different found configurations. For each configuration represented by a raw in the tables, we give the total number of TRXs, *nb*TRX, computed to reach the blocking threshold represented by the column 1, GoS. We also give an estimation of the lost traffic (*Erlang*) due to blocking rate as well as the interference cost (function *F* defined by the formula (11)) of the frequency plan found for this threshold. The three last columns, *lost traffic*, represent the traffic loss (*Erlang*) due to interference according to three quality thresholds: 7% FER, 4% FER and 2% FER. A software tool for FER *evaluation*[2] estimates the traffic loss due to interference. Each quality threshold refers to the percentage of erased frames above which communications are considered bad, and then 2% is the hardest threshold. We underline the 2% blocking rate lines as reference.

The conflicting nature between blocking and interference is clearly observable in the two tables. In Table 3, the blocking rate from $\text{GoS} = 0.01$ to $\text{GoS} = 0.02$ leads to a loss of 6.02 *Erlang* as blocked traffic, but at the same time it leads to a gain of 6.82 *Erlang* considering the lost traffic at 7% FER. The global result on carried traffic is identical but the cell capacity configuration and network cost are not: to gain 1% of call blocking rate, we add 63 transceivers, for nothing while the traffic gain is loss by the additional interference volume. More generally, we see on Table 1 that from 0.7% to 2% of blocking rate, the global traffic loss using 7% of FER as reference is identical. Cell capacity growth reduces the traffic blocked but the lost traffic from interference is growing as well. We observed the same behaviour on the second network but with a lower load.

If we look at a tighter FER reference, 2% for instance, we do not get the same best result. A tighter FER is corresponding to best radio quality requirement. Higher rate services such as data services will consider this tighter value. On Table 3, the best compromise is got for 5% of

Table 3 Characteristics of configurations for network B_381

GoS	*nbTRX*	*Blocked traffic (Erl)*	*Interference cost*	*Lost traffic 7% FER (Erl)*	*Lost traffic 4% FER (Erl)*	*Lost traffic 2% FER (Erl)*
0.007	1115	2.78	908,334	129.04	203.12	313.24
0.008	1105	3.31	875,781	126.14	198.08	307.09
0.009	1092	4.18	854,864	127.60	203.11	310.90
0.01	1085	4.72	820,273	126.85	199.73	301.91
0.02	1022	10.74	740,353	120.03	188.20	287.50
0.03	989	15.48	687,799	121.29	192.64	287.14
0.05	941	27.07	602,297	110.64	174.99	267.40
0.1	858	77.53	474,644	97.66	158.10	253.55
0.2	744	206.35	309,604	76.54	130.64	204.61
0.4	570	594.96	136,358	38.36	64.20	108.47

Table 4 Characteristics of configurations for network BM_120

GoS	*nbTRX*	*Blocked traffic (Erl)*	*Interference cost*	*Lost traffic 7% FER (Erl)*	*Lost traffic 4% FER (Erl)*	*Lost traffic 2% FER (Erl)*
0.007	179	0.4937	5029	0.86	1.95	4.16
0.008	175	0.5642	4430	0.79	1.56	3.62
0.009	175	0.5642	4833	0.93	1.87	3.74
0.01	175	0.5642	4914	0.90	2.08	3.96
0.02	168	0.9147	3224	0.62	1.47	2.96
0.03	160	1.5439	2896	0.61	1.44	2.72
0.05	150	3.1563	2233	0.44	1.01	1.94
0.1	135	7.7643	1005	0.14	0.43	0.99
0.2	127	15.2727	749	0.14	0.29	0.67
0.4	123	23.1869	458	0.06	0.17	0.38

call blocking with 27.07 + 267.40 = 294.47 *Erlang* as total loss traffic. Moreover, this call blocking rate requires 941 TRXs instead of 1022 at 2% that is a lower network cost. This result clearly shows that the increasing of the number of TRXs to get a higher throughput does not necessary lead to a lower lost traffic and to the expected result. Note that the lower load network in Table 4 does not reproduce this result.

The tradeoffs we obtained illustrate that the current methods for traffic capacity management, which are only based on call blocking estimation, are not sufficient to get a good understanding of network behaviour. As well we broke the restriction in the configurations of solutions of the previous works on the domain. The multiple configurations given in the tables facilitate the human decision in the capacity planning process. The proposed method computes a set of cell capacity configurations and global traffic loss data, which constitute the basis for the decision maker's choice inside the tradeoff between traffic load and capacity investment.

4 Conclusion and perspectives

Cell capacity planning includes two opposite criteria rarely tackled together: blocking rate and interference. On one hand, the decision maker likes to increase cell capacity in order to load more traffic. On the other hand, the decision maker wants to reduce interference caused by the intensive reuse of available frequency channels. Knowing that these two phenomena of blocking and interference lead to traffic loss.

In this paper, we proposed a bicriteria formulation for the cell capacity planning problem. This approach takes simultaneously into account both conflicting aspects. We used an analytical model allowing the estimation of the offered traffic data for cell capacity and frequency planning steps. We also proposed an optimisation technique based on the *Epsilon-constraint* method. The idea is to vary the call blocking rate threshold iteratively and to analyse the impact on the tradeoff between lost traffic from blocking and interference. The approach proposes a set of solutions for cell capacity planning. The set corresponds to non-dominated tradeoffs between lost traffic due to blocking rate and lost traffic due to interference. The final choice of the tradeoff naturally belongs to the decision maker.

We did experiments with the development of both modules: offered traffic computation and cell capacity computation. We tested the efficiency of both modules with data sets from real networks. The offered traffic computation from the analytical model gave a good approximation of effective traffic. We compared the approximation to the offered traffic from a simulator and it gave low errors for low call blocking rates. Within the cell capacity module, the bicriteria model and the *Epsilon-constraint* optimisation technique offer an effective way to manage the blocking/interference tradeoff. We got a set of network configurations for two scenarios of traffic loads that allows the decision maker to compare several distribution of traffic loss from call blocking rate and interference for different cells capacity. These data are completed by the number of TRXs on the stations, which represents the investment linked to the real additional carried traffic.

In this paper, the model proposed may be further reinforced. A first direction is to distinguish the traffic channels according to their nature, as traffic channels on BCH or TCH, and voice or data transmission. This will bring several evaluation criteria for the computation of interference: hopping or nonhopping TCH, several FER percentages, etc. In addition, the TRXs dimensioning should take into account the coverage loss due to the use of couplers while their number increases; it modifies the interference computation in the frequency assignment step.

Cell capacity planning is also related to handover procedure. An additional optimisation criterion may then be introduced to measure the blocking rate due to *handover*. Typically, to face this problem, some traffic channels called guard channels are dedicated to *handover* attempts (Pla and Casares, 2003). The dimensioning of the guard channels becomes an additional aspect of cell capacity planning.

Finally, the installation of new TRXs raises the problem of the financial cost involved by such operation. A supplementary economical criterion comes to be added to the problem formulation. In our current approach, the criterion is a global result given by the number of added TRXs and does not take into account an economical measurement per operation.

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Notes

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[2] PARCELL, France Telecom engineering tool.