

Managing Capacity for a Real Multi-Service UMTS/HSPA Radio Access Network

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Abstract

Nowadays, the mobile networks utilization is high, which implies that an efficient resource network management must exist. This project has the goal to study and develop a simulation multi-service platform based on admission curves for Third Generation (3G) networks. These curves define the maximum limit of resource utilization for a certain defined Grade of Service (GoS).

To achieve this goal, the Multidimensional Erlang-B method is studied and implemented. Its input parameters are considered, taking in to account real statistics. After, the admission curves are presented and validated. The used statistics are from a real mobile operator, which implies to study the Key Performance Indicators (KPIs) for the operator's specific vendor.

4 different cells are studied and they show different results, depending on the input statistics. If they include weekend days, the error between the statistics position and the admission curve is around 5.4% while if they do not include weekend days, the error decreases to 2.5%. Another analysis is related with the Base Station (BS) transmit power. There are cells with 30% more power than necessary and other cells with 40% lack of power. However, the data rate assigned to each user is lower than the promised by the operator. In the end, an analysis of the BS parameterized power is performed, with the optimized value as output, according with the interval between the admission curve and the statistics.

Keywords: Mobile Networks, High Speed Packet Access, Capacity, Multidimensional Erlang-B Model

1. Introduction

Currently, 3G has a penetration around 80% worldwide, and 85% penetration is expected in 2020 [1]. In fact, the used traffic from the network is increasing, and the operators will have to manage the increasing capacity.

Moreover, the data rates claimed by the subscribers are also higher, asking for a greater effort from operators to answer all these needs.

Another claim is related with the admission control and quality, since users are required to have low call dropping and call blocking ratios.

Hence, the operator has to improve the management of the network resources. An used technique is the admission control, approached in this thesis. The admission control will define a curve, which is resource limited. This curve will depend on the required Quality of Service (QoS) and on the desired blocking probability. The admission region will also control usage between services, since, in 3G, there are services like voice, streaming or High-Speed Downlink Packet Access (HSDPA), therefore a real multi-service working platform.

1.1. Objectives

This project addresses the need to manage the BS capacity, helping with the congestion control and QoS provisioning [2].

The result will be an admission control curve, depending on some cell characteristics, which will be defined throughout the paper. The curve will manage traffic between two services.

To the admission curve representation, real network performance statistics from the respective BS will be added, in order to compare the theoretical capacity curve with the real BS behaviour. This will help to understand if the BS has more or less radiating power than it should, or if the target data rate is too ambitious.

1.2. Related Work

In the scope of this paper, there are already some studies in the Call Admission Control (CAC) area, as in [3–5]. The Multidimensional Erlang-B Model was also developed in [6].

1.3. Document Structure

This paper is structured as follows: in section 2 an overview of the 3G technology is given, specially the power split for all the services, in section 3 is explained the Multidimensional Erlang-B method and the process to find the number of power slots, in section 4 is presented the graphic results and in section 5, conclusions will be drawn.

2. Radio Network Planning

Wideband Code Division Multiple Access (WCDMA) is the adopted air interface in the 3G, in particular in Universal Mobile Telecommunications System (UMTS), aiming to improve communication quality, high quality image and video transfer and to achieve higher data rates. Some requirements are, for example, transmission rates up to 2 Mbit/s and the coexistence with the Second Generation (2G) systems (Release 99).

2.1. Power Allocation

The BS is parameterized with a maximum transmit power, P_{Total} , which is calculated, in 3G, by:

$$P_{Total} = P_{HSDPA} + P_{DCH} + P_{CCH} \quad (1)$$

where P_{HSDPA} is the used power for the HSDPA service, P_{DCH} is the power for Dedicated Transport Channel (DCH) and P_{CCH} is the power for control channels.

P_{DCH} comprises the power for Circuit Switch (CS) and Packet Switch (PS) services. The CS includes the voice service, in different bit rates (from 4.75 kbit/s to 12.2 kbit/s) and the PS combines the conversational, streaming, interactive and background classes, in different bit rates as well (from 8 kbit/s to 384 kbit/s).

The P_{CCH} is mapped in different physical channels. It is parameterized and it does not depend on the number of users that are allocated to the network. It is always being transmitted, even if the User Equipment (UE) is in idle mode.

However, the voice is normally a priority service, when related with PS and HSDPA services [27]. This implies that there is only enough power available for HSDPA after the voice users being served. Additionally, the power for each service floats over time, as in Figure 1.

2.2. Erlang Traffic Model

The voice traffic is measured in Erlangs. As in [8], an Erlang "represents the amount of traffic intensity carried by a channel that is completely occupied (i.e. 1 call-hour per hour or 1 call-minute per minute). For example, a radio channel that is occupied for thirty minutes during an hour carries 0.5 Erlangs of traffic".

Usually, the traffic is measured in the busy hour and it is given by the Erlang-B model, which has, as

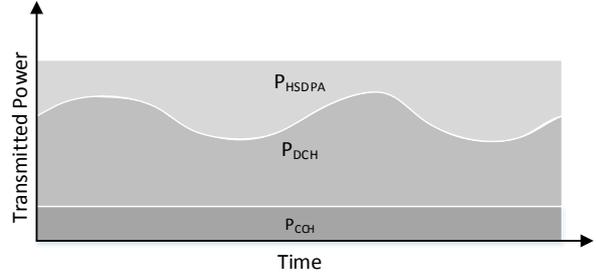


Figure 1: Power allocation for Control Channel (CCH), DCH and HSDPA (based on [7]).

input parameters, the GoS and number of circuits. The GoS, or blocking probability, is the probability that all the channels will be busy when a phone call is made. The circuits are the structure to handle the calls.

With the traffic and the number of circuits, it is possible to calculate the blocking probability, p_B , as:

$$p_B = \frac{\frac{\rho^C}{C!}}{\sum_{x=0}^C \frac{\rho^x}{x!}} \quad (2)$$

where ρ is the offered traffic and C is the number of circuits [9].

The Erlang-B model can only be used if the capacity is hard blocked, *i.e.*, the system capacity is limited by the amount of hardware. If the system is soft capacity limited, which means that it is limited by interference, the Erlang-B model will give pessimistic results.

2.3. Channel Quality Indicator (CQI)

The CQI is a control information, which depends on the connection quality. It is bounded between 1 and 30, where 30 is the maximum possible. Using the CQI, it is possible to calculate the maximum data rate for the user, since the CQI tables give the Transport Block Size (TBS). It also depends on the mobile category, which must be given by the control information as well [10]. The data rate, $R_{achievable (MAC-hs)}$ is given by the equation:

$$R_{achievable (MAC-hs)} = \frac{V_{TBS} \times (1 - BLER)}{0.002 \times I_{TTI}} \quad (3)$$

where V_{TBS} is the TBS and I_{TTI} is the inter Transmission Time Interval (TTI) interval.

A TTI is the duration of a data transmission and, in HSDPA, is equal to 2 ms. The inter-TTI interval is the distance between the beginning of a TTI and the beginning of the following one. Normally is equal to 1.

In HSDPA, there are two downlink physical channels, the High Speed Shared Control Channel (HS-SCCH) and the High-Speed Physical Downlink

Shared Channel (HS-PDSCH). The first one is a control channel and has a Spreading Factor (SF) of 128 and the second one is a data channel, with a SF of 16. Each channelization code corresponds to one HS-PDSCH code, with a maximum of 15, since the last is used for signaling. One user can use 1 code up to 15 codes, at the same TTI, however it is usual to spend 5, 10 or 15 codes. This means that, in the minimum, there is only one HSDPA user, when the user needs 15 HS-PDSCH codes and, in the maximum, 3 HSDPA users, when each user utilizes 5 HS-PDSCH codes [11].

3. Implementation

The admission curve is set in a Cartesian x-y graph and it has, in the axes, the traffic for each service, in Erlang. To build the curve, the Multidimensional Erlang-B Model is used. To find the input parameters for that model, it is computed two cell characteristics, one for each service.

3.1. Multidimensional Erlang-B model

The Multidimensional Erlang-B model appeared with the necessity to calculate the blocking probability of a group of independent traffic streams, with arrival rate λ_i and service rate μ_i . It considers five input parameters: J , which is the number of carriers, \mathbf{K} , which is the capacity of each carrier, S , which is the number of services, \mathbf{M} , which is the mapping matrix and δ , which is the blocking probability for each service.

The mapping matrix is a representation of the carrier capacity utilization, by service, where the lines symbolize the carrier and the columns symbolize the service. This means that, the line 1 and column 1 indicates how many capacity units will be used to allocate one user to the carrier and service 1. The units of capacity can be, for example, bandwidth.

Numerical values are used in order to explain the concepts:

- $J = 2$;
- $\mathbf{K} = [30 \ 30]$;
- $S = 2$;
- $\mathbf{M} = \begin{bmatrix} 1 & 4 \\ 4 & 1 \end{bmatrix}$;
- $\delta = [2 \ 2]\%$.

With this numerical inputs, it is possible to take that, in carrier 1, the service 1 will need 1 unit of bandwidth while the service 2 will need 4 units. So, it is possible to allocate 30 users to service 1 (if the service 2 is not in use) but only 7 users maximum in service 2, since the total carrier capacity divided

by the 4 units of bandwidth per user is $30/4 = 7.5$, which has to be round down.

To apply the Erlang-B model, discussed in section 2.2, using the number of users as the circuits, the maximum traffic, in carrier 1, for service 1 is $\rho_1 (30 \text{ circuits}, 2\%) = 21.93 \text{ Erl}$ and for service 2 is $\rho_2 (7 \text{ circuits}, 2\%) = 2.94 \text{ Erl}$.

In this method, the probabilities of being in the different states are calculated and, after, it is computed the blocking probability. The probability of being in one state depends on the used bandwidth from each service.

A state is define as (i,j) , and a increment of 1 indicates that one more user is served. This means that, with the numerical values announced before, the state (1,1) is the case of one user using service 1 and one user using service 2 and, consequently, 5 units of bandwidth are spent, because the service 2 needs 4 units of bandwidth. Generalizing, having the matrix \mathbf{M} equal to $\begin{bmatrix} a & b \\ c & d \end{bmatrix}$ and the state represented by (i,j) , the state probability is the probability to be using $i*a$ capacity for service 1 and $j*b$ capacity for service 2.

With this state definition, it is possible to design a diagram that shows the dependencies between the states and the resources limits, see Figure 2.

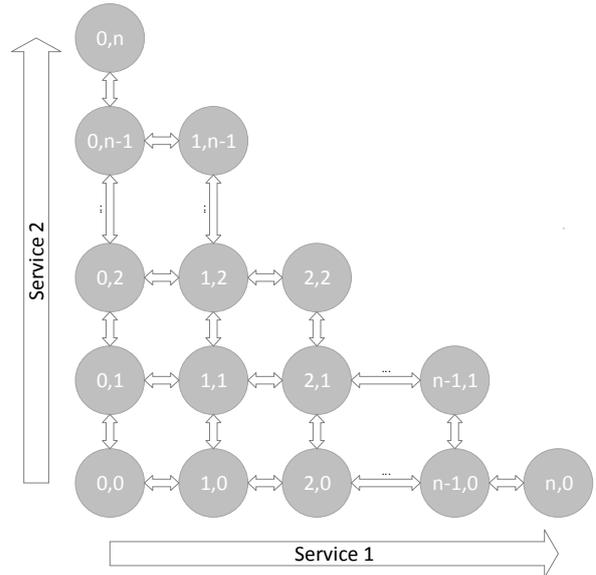


Figure 2: Two-dimensional state transition diagram.

The state transition diagram (Figure 2) assumes that the horizontal direction represents service 1 and the vertical direction represents service 2. Moving from the state (0,0) to state (1,0), means that it is being used $1*a$ circuits for traffic class 1 and $0*b$ circuits for traffic class 2. But if it goes into the top direction, to state (0,1), it means that it is being used $0*a$ circuits for traffic class 1 and $1*b$

for traffic class 2.

The state probability is given by:

$$p(i, j) = Y \cdot \frac{\rho_1^i}{i!} \cdot \frac{\rho_2^j}{j!} \quad (4)$$

where ρ_1 and ρ_2 is the pair of offered traffic and Y is the normalization constant and it is calculated by:

$$Y = \frac{1}{\sum_{\nu=0}^K \frac{(\rho_1 + \rho_2)^\nu}{\nu!}} \quad (5)$$

where \mathbf{K} is the capacity.

The blocking probability depends on the available bandwidth from the capacity. Taking the numerical values as example, in resource 1, service 1 is blocked when it does not have any free bandwidth. However, service 2 is blocked when it does not have any unit of bandwidth, but also when it only has one unit of bandwidth, two or three. If it has four units of bandwidth, it is already possible to add one more connection of service 2. So, with an offered traffic ρ_1 and ρ_2 , the blocking probability, represented by p_b , for service 1 and 2 is:

$$p_b(1) = p(i + j = 30) = p(30, 0) + p(26, 1) + p(22, 2) + \dots + p(2, 7) \quad (6)$$

$$p_b(2) = p(i + j = 30) + p(i + j = 29) + p(i + j = 28) + p(i + j = 26) \quad (7)$$

Since it has two carriers, the blocking probability has to be calculated for both of them, and after that, the maximum blocking probability between the two carriers is compared with the blocking probability limit.

Applying the previous method in Matlab ©, the resulting curve is in Figure 3.

This simulation is in accordance with the expected values. When ρ_1 is equal to 0, no user is using the service 1, ρ_2 is equal to 2.94 Erl and the same when ρ_2 is equal to zero.

3.2. Number of users determination

The maximum number of users depends on the maximum number of power slots, according with the BS maximum power, P_{Total} . The power slots are sketched in Figure 4.

Each service has a cell characteristic, that depends on real statistics, measured during multiple days. For voice, the cell characteristic is called *Energy Per Bit (EPB)*, in mJ/kb and it is given by equation (8).

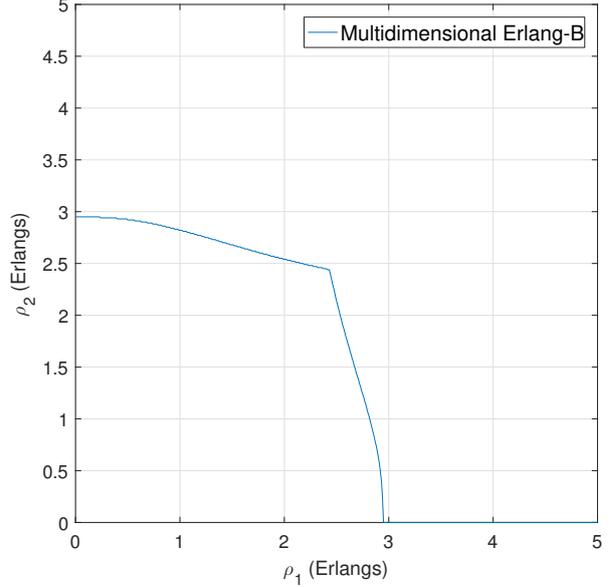


Figure 3: Multidimensional Erlang-B.

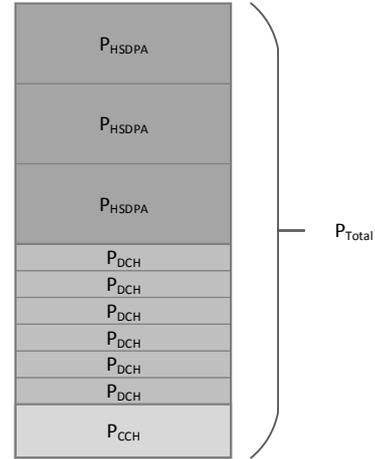


Figure 4: Power slots of CCH, DCH and HSDPA.

$$EPB = \frac{\sum_{samples} (P_{DCH} \times R_{MAC-d}^2)}{\sum_{samples} (R_{MAC-d} \times R_{MAC-d}^2)} \quad (8)$$

P_{DCH} is the power for dedicated channels, without the control channels and the R_{MAC-d} is the bit rate used in DCH channels.

In HSDPA, the cell characteristic is the $\bar{P}_{DSCH-TX}$, which is the required power to serve one user, according with a target data rate. The $\bar{P}_{DSCH-TX}$ is equal to:

$$\bar{P}_{DSCH-TX} = \frac{P_{DSCH-TX} \times d \times \eta}{I_{TTI}} \quad (9)$$

The $P_{DSCH-TX}$ is the mean power used for the HSDPA service. The d stands for duty cycle, which is the ratio between the target data rate, defined by

the operator, and the achievable data rate, calculated as in equation (3). η is the activity factor and it gives an utilization ratio for the TTIs.

In Table 1 an example for Energy Per Bit and $\bar{P}_{DSCH-TX}$ in a cell is shown, located in an urban area, and also the respective maximum number of users for voice and HSDPA service.

Cell	3
$P_{max\ BS}$ [dBm]	46
Energy Per Bit [kJ/mb]	0.0998
Voice users	29
$\bar{P}_{DSCH-TX}$ [W]	1.455
HSDPA users	24

Table 1: Example of values for Energy Per Bit and $\bar{P}_{DSCH-TX}$ and respective voice and HSDPA users.

3.3. Admission Curve

With the results from the previous section, it is possible to construct the matrix \mathbf{M} and the vector \mathbf{K} , in order to use them as input parameters for the Multidimensional Erlang-B Model. However, statistics from one carrier are used, hence the capacity \mathbf{K} is a value equal to the maximum value of power slots between both services and the mapping matrix \mathbf{M} is a vector, where the position corresponding to the service with higher number of power slots is equal to 1 and the other position is equal to the maximum number of power slots and divided by the minimum number of power slots.

Statistics are added to the admission curve, in order to validate the algorithm. The statistics are not in Erlangs, meaning that the used traffic must be calculated. Since one Erlang is the occupation of a channel during one hour, as in section 2.2, and the statistics are taken for half an hour, the used traffic in voice is equal to the average number of voice users multiplied by 30 minutes and divided by 60 minutes. In the HSDPA case, is necessary to have in account a ratio between the target data rate and the throughput of that half an hour, because the traffic transmitted in half an hour with a data rate of 500 kbit/s is half of the traffic transmitted in half an hour with a data rate of 1000 kbit/s.

4. Case Study Analysis and Validation

In all simulations, the blocking probability for voice is 1% and for HSDPA is 50%, because the target data rate is equal to the average data rate registered in the statistics. That can be assumed because the average data rate is equal to the median data rate and the CQIs distribution is approximated to a normal one with a significance level of 2%, according to the Lilliefors test.

The first admission curve is generated from a cell located in an urban scenario, in the busy hour. 38 days of statistics are available, the target data rate is equal to the average throughput and the CQI is equal to the median value. The average transmitted power is similar to the BS maximum transmit power, which means that the statistics should be around the admission curve. The resulted graphic is in Figure 5.

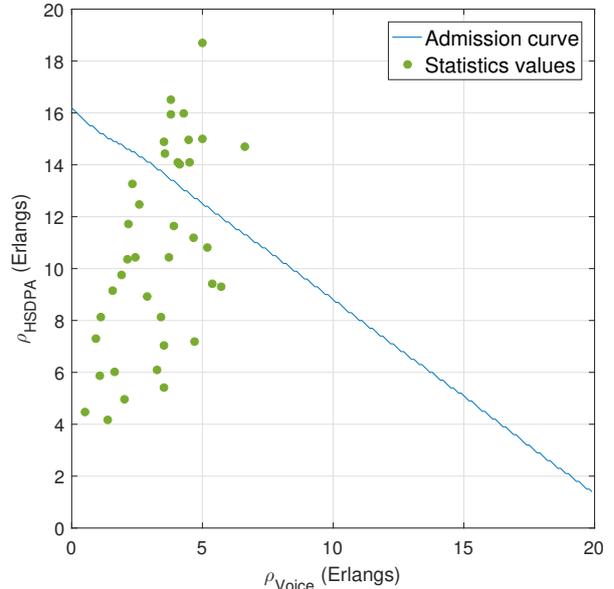


Figure 5: Admission curve and respective statistics for cell 3.

As expected, the statistics are around the admission curve. The values above the curve have lower throughput and some points below the curve are using less power than the maximum BS transmit power. In a real situation, a lot of factors interfere with the results, for example, if it is weekend or week day. Normally, in the weekends, the throughput attributed to each user is higher than in the week days, specially if the BS is located in a business area.

The next results are used to validate the algorithm. Specific days are chosen, from the statistics, denominated by reference values. The admission curve is calculated considering R_{target} and BS transmit power equal to the throughput and to mean used power, respectively, from that chosen reference value.

After a validation error can be computed. Let us define the validation error as the distance between the reference value and the admission curve, since the admission curve is dimensioned for the reference value mean used power.

The admission curve for cell 3, on July 7th 2016 at 17:00, is in Figure 6, with the R_{target} equals to

534.12 kbit/s and transmit power equals to 45.64 dBm (36.64 W).

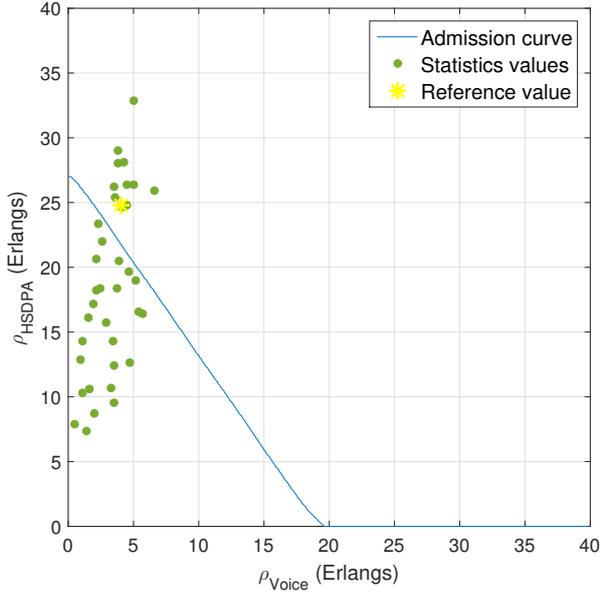


Figure 6: Admission curve for cell 3 for all days with $P_{max\ BS}$ equal to the used power on July 7.

The reference value is above the curve with a validation error of 4.98%. The same test is done for input statistics from week days only, which corresponds to 29 days. Figure 7 presents the admission curve with the same blocking probabilities as in Figure 6.

In this measurement, the validation error is equal to 1.02%. For this cell, at the busy hour of July 7th, the admission curve has a better performance when the statistics only have week days than when they have all days (week and weekend days).

The second test is for cell 1, at 13:00 and with a reference value relative to May 27th. The simulations are made for all days of the week and after, only for week days, in order to compare the error between both.

The BS transmit power is manually changed again, matching the used power in the specified half an hour. So, $P_{max\ BS}$ is equal to 35.56 W and the R_{target} is equal to 521.25 kbit/s.

Figure 8 presents the admission curve, obtained with the statistics from all days of the week, which corresponds to 38 days.

The error in Figure 8 is equal to 9.43%. Again, the same case is simulated for statistics including week days, in a total of 29 days, and the admission curve is in Figure 9.

The error in this case decreases from 9.43% to 7.44%, confirming that the cell characteristics are better defined when the input statistics only include

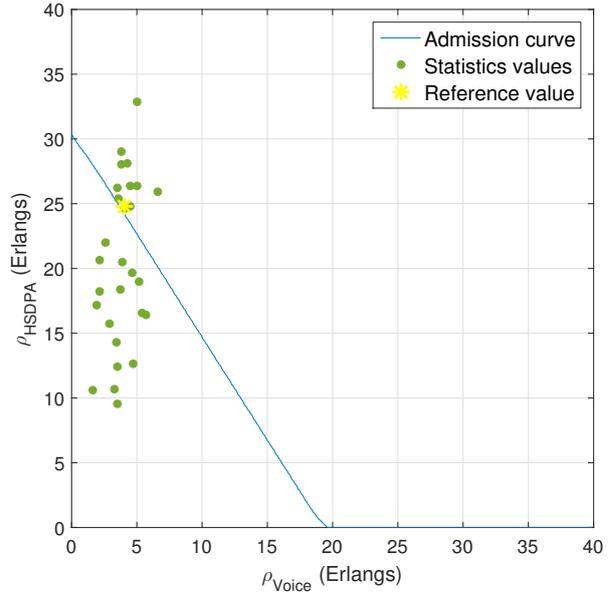


Figure 7: Admission curve for cell 3 for week days with $P_{max\ BS}$ equal to the used power on July 7.

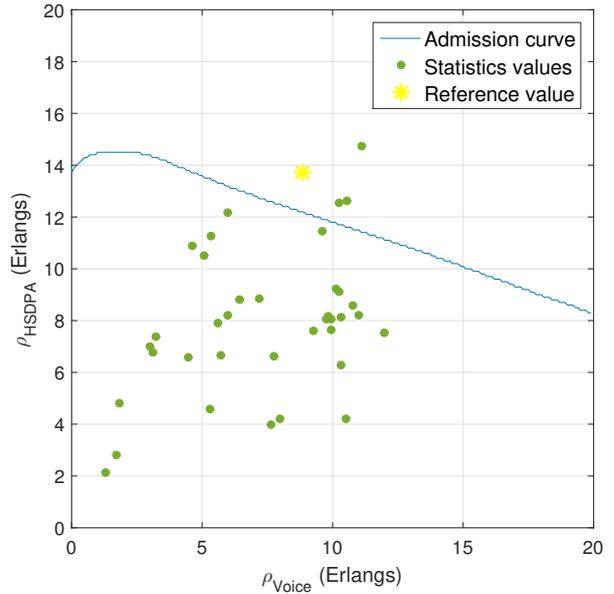


Figure 8: Admission curve for cell 1 for all days with $P_{max\ BS}$ equal to the used power on May 27th.

week days.

A last introduced feature is the headroom. The headroom is a percentage value that indicates if the BS transmit power is in excess or in lack and expresses which transmit power should the BS have allocated.

That headroom is calculated taken in account a

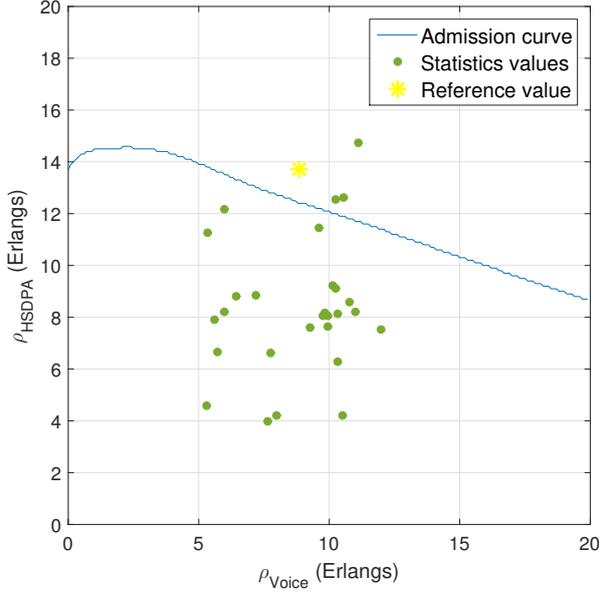


Figure 9: Admission curve for cell 1 for week days with $P_{max\ BS}$ equal to the used power on May 27th.

reference traffic, which should be a percentile of all the statistics. After the reference traffic calculation, it is computed the difference between the reference traffic and the admission curve.

The chosen percentile for the reference traffic is 80, so it is compared the difference between the percentile 80 with the admission curve. Figure 10 shows an admission curve for cell 3, with the reference traffic.

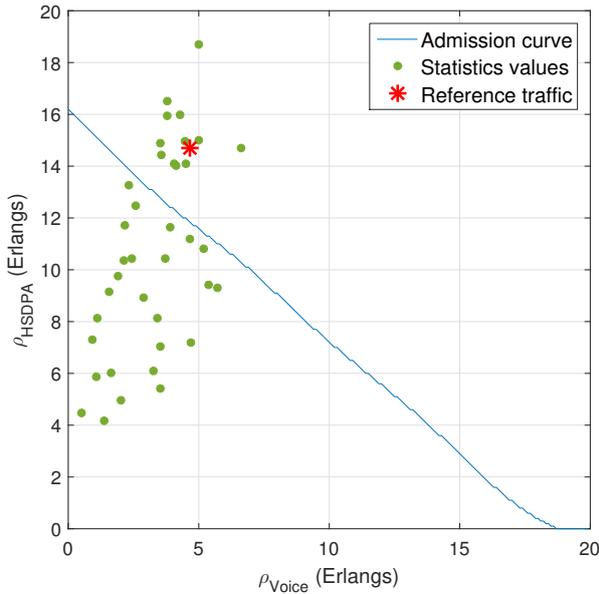


Figure 10: Reference traffic for cell 3.

The output message says that the cell has a nega-

tive headroom equal o 14.75% and the BS transmit power should be equal to 45.1 W, in order to aggregate 80% of the statistics, at least. So the BS transmit power was changed to the suggested one and the new admission curve is presented in Figure 11.

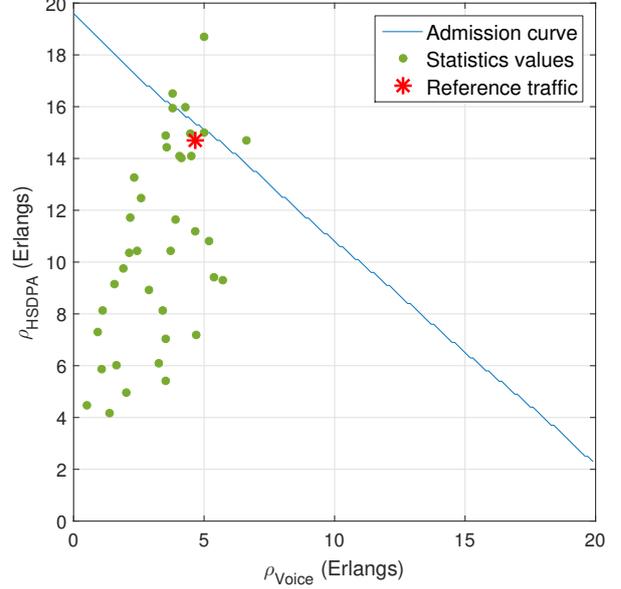


Figure 11: Admission curve with the BS maximum power changed.

The admission curve is shifted up and now it includes the reference traffic and 80% of the statistics. This analysis can be really useful to find the proper BS transmit power, according with the past traffic.

5. Conclusions

The goal of this project was to study and develop a simulation multi-service platform based on admission curves for 3G networks. These curves define the maximum limit of resource utilization for a certain defined GoS.

To validate the admission curve approach, statistics were added. With them, the used power, the number of users for each service and other important parameters are known.

The main results and conclusions are related with the Multidimensional Erlang-B model and the implemented admission curves.

The Multidimensional Erlang-B Model provided the best results of the four methods, which were studied and implemented. It is the only one that can combine the dependencies between the services and the exact results of the offered traffic for each service. The model was also tested for several examples and it varied according with the expected.

In section 4, two conclusions were drawn: the admission curve is better defined when the input statistics are working days, instead of working days

plus weekend days, and it is also better defined when there are more day samples. The maximum validation error was 9.43%, which brings reliability to this research work.

A last conclusion goes to the parameterized BS transmit power. From the 4 analysed cells, two of them had more BS transmit power than the necessary, against the other two, which had less transmit power than the required to agglomerate 80% of the statistics. More alarming is the throughput, since the registered throughput in the specific KPIs are lower than the promised by the operator, which is around 2 Mbit/s. The average throughput in the busy hour is always around 700 kbit/s.

It is possible to improve this project with the introduction of 3-D admission regions. Since 3G has more services than voice and HSDPA, such as PS services, it is possible to relate 3 services. After the performed validation for 3G, the new goal should be the addition of Long Term Evolution (LTE) technology.

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