Degradation of Service Modelling and Investigation in WCDMA Mobile Communications

Ismat Aldmour and Khalid Al-Begain,
Faculty of Advanced Technology, University of Glamorgan, UK
E-mail: ialdmour, kbegain @ glam.ac.uk

Abstract

Erlang capacity is the average traffic tolerated by the network that is hard limited by a certain number of servers, the active user capacity, at a certain acceptable blocking percentage. In WCDMA, contrary to GSM or analogue AMPS, interference limits the active user capacity which means that we don’t have a hard limit on the number of users and therefore obtaining the Erlang traffic capacity is not a direct problem.

However, a model for WCDMA active user capacity boundaries, on the uplink, is obtained which relates the maximum capacity of any service class to the number of users in other service classes. This enables the usage of Erlang B formula to calculate the blocking on a service by service basis. In this work, an overall performance parameter, Degradation of Service, DoS, is defined as a linear combination of all blocking percentages for the different services and is studied for the points on the flexible active capacity boundary. It is shown that this parameter can be useful for selecting a suitable operating point on the boundary for a given traffic as well as in the case of relaxed WCDMA cell operating below the boundary.

Keywords: WCDMA, Degradation of Service, UMTS, Capacity, Coverage

1. Introduction

Erlang traffic models are well established traffic models that have been used for a long time in the dimensioning of landline telephone systems. They were also used for the dimensioning of mobile systems as in [1] for GSM/GPRS and [2] for CDMA. Erlang capacity for a network that is hard limited by a certain number of servers, i.e. certain active user capacity, is the average traffic tolerated at a certain acceptable blocking percentage. In WCDMA, contrary to GSM or analogue AMPS, interference limits the active user capacity which means that we don’t have a hard limit on the number of users. This means that obtaining the Erlang traffic capacity is not a direct problem. Two things complicate the problem of traffic analysis in WCDMA [3]. First thing is that cell coverage is not fixed and varies with interference level in the network. The second thing is the provision for multiple data rates which further complicates the estimation and prediction of interference levels and the cell edge.

In literature, the determination of traffic capacity using Erlang or similar distributions has been mainly based on the use of the pole capacity as the hard limit on the number of servers. Pole capacity is obtained for the single service case [4][5][6] using interference limit analysis (load analysis) which takes into consideration the bounding due to interference only with no consideration to the capacity and coverage interaction and propagation environment effect.

Pole capacity based on interference limit only is considered accurate enough only in micro-cells. As cells grow up in size, reduction in the number of serviceable users occurs due to the increased propagation losses on the uplink [7].

In a WCDMA cell with a mixture of service classes, the maximum number of users of any service class that can be active at any instant of time is not a fixed value and is dependent on present numbers of other users in other services. Therefore, given a certain target operating point as a mixture of services with certain number of active users in each service, we may use Erlang B formula to calculate blocking rate for any class at certain offered traffic load of users of this class (or calculate traffic tolerated given the blocking using the reverse formula). This target should be a feasible operating point, i.e. the combination of the different number of users of the different services is a valid combination that doesn’t end in exceeding capacity boundaries (defined through meeting a target set of signal to noise ratio thresholds) or in reducing coverage to below the target cell radius.
In [8] the active user bounding capacities were given on the uplink for a certain cell coverage radius on a service by service basis in WCDMA\(^1\). These boundaries define the admissible space where target working points may be defined on or below it.

In this work, we first review the model for WCDMA bounding capacities and the main parameters affecting these capacities. We define an overall Degradation to Service, DoS, parameter as a function of the blocking probabilities of all services. The behavior of this parameter is investigated for the case of a mixture of two services in order to make some conclusions graphically. Investigation of the attitude of this parameter with changing traffic, cell radius and with the different proportions of the different services will be done. This enables planning the mix of services that guarantees a certain aggregate blocking given by DoS.

The rest of the paper is organized as follows: Section 2 revises the traffic model and Erlang B formula. Section 3 presents the WCDMA capacity bounding model. The DoS parameter is defined and investigated in section 4. Section 5 summarizes the results. Conclusions and suggestions for further research are given in section 6.

2. The Traffic Model

In a multiservice environment we have \(Q\) different service classes each service of which is served using a number of servers \(N_q\). We will first assume independent selection of the number of servers of each service class, and that the traffic of each service class is a lossy traffic where no waiting is assumed. The blocking rate \(B_q\) for any service class \(q, q=1 \ldots Q\), with its users offering a traffic of \(A_q\) Erlang, is calculated using Erlang B formula

\[
B_q = \frac{A_q^{N_q}}{N_q! \sum_{n=0}^{N_q} \frac{A_q^n}{n!}}. \quad (1)
\]

To best determine on a certain service mix a certain parameter must be defined that can used to give quantiative value to the grade of service of the mix. We chose to define Degradation of Service or DoS parameter\(^2\) to be a linear combination of all blocking rates given by DoS.

\[
\text{DoS} = \sum_{q=1}^{Q} w_q B_q, \quad (2)
\]

where \(w_q\) is a weight factor for service \(q\).

3. WCDMA Bounding Model

The formula for the maximum number of active users \(N_{\text{max}}\) of any service class \(q\), in a system with \(Q\) different classes, was shown [8] to be composed of three parts as follows:

\[
N_{\text{max}} = N_{u_q} - N_{pl_q} - N_{\text{others}_q}. \quad (3)
\]

The first term, \(N_{u_q}\), represents the upper limit on number of users of service \(q\) limited by interference only (users in neighboring and others using the same service). This is the interference bounding limit and is dependent only on the parameters of the service itself and interference conditions from neighboring cells. It is independent from distance and propagation conditions. The second term, \(N_{pl_q}\), represents the reduction value in capacity for service \(q\) due to power limitation imposed by distance and propagation conditions. It is shown to be proportional to the distance raised to the power \(1/C_p\) where \(C_p\) is the propagation constant of the environment. For a given cell radius, the value

\[
N_{\text{service}_q} = N_{u_q} - N_{pl_q}. \quad (4)
\]

is constant and represents the capacity bound of service \(q\) if no users of other services exist in the system. Thus, it is called the Service Capacity of service class \(q\) (for the given radius). The third part in (3), \(N_{\text{others}_q}\), is the reduction in capacity of service class \(q\) due to the presence of other users using other services (in the same cell) due to their interfering effects on the capacity of the service \(q\).

For a given cell radius, the formula in (3) can be rewritten as

\[
N_{\text{max}_q} = N_{\text{service}_q} - N_{\text{others}_q}. \quad (5)
\]

The value \(N_{\text{others}_q}\) of class \(q\) can be expressed as the sum of the effect of all other users in other services as given by

\[
N_{\text{others}_q} = \sum_{\hat{q}=1}^{Q} \alpha_{\hat{q}q} N_{\hat{q}}. \quad (6)
\]

where \(N_{\hat{q}}\) is the number of users in service class \(\hat{q}\) and \(\alpha_{\hat{q}q}\) is a parameter representing the relative interfering

\(^1\) Although these limits were given in the reference for the case of special antennae, the results are applicable to WCDMA in general.

\(^2\) Blocking is usually referred to as Grade of Service, GoS, while increased blocking means degradation to service so we are correcting the concept here.
effect of one user of service $\hat{q}$ on service $q$. This parameter, $\alpha_{q\hat{q}}$, depends on factors like the relative ratio of the voice activity factors of the two services, $v_q/v_{\hat{q}}$, and the relative ratio of spreading factors $S_q/S_{\hat{q}}$ (or data rates ratio $R_q/R_{\hat{q}}$).

For a system of two service classes, the set of feasible combination of number of users of the two classes $\{N_1, N_2\}$ are those satisfying the inequalities given by

\[
N_1 \leq N_{\text{service}_1} - \alpha_{12} N_2 \\
N_2 \leq N_{\text{service}_2} - \alpha_{21} N_1 \\
N_1, N_2 \geq 0
\]  

(7)

Notice that the equality holds for points on the capacity boundary. When plotted on a 2 dimensional plane with axes representing $N_1$ and $N_2$ then the intersection of any of the lines corresponding to any service with its axis is the service capacity of that service while the slope represents the $\alpha$ factor. In the case given by Figure 1, service 1 has a service capacity of 175.1 and service 2 has a service capacity of 57.9 users with parameters $\alpha_{12}=2.19$ and $\alpha_{21}=0.229$. Therefore, the boundary equations are

\[
N_1 \leq 175.1 - 2.19 N_2 \\
N_2 \leq 57.9 - 0.229 N_1
\]  

(8)

The active user capacity in WCDMA system decreases with increased cell coverage. This reduction is due to the limit imposed on the link because of the increased distance and loss along the path. Thus the signal arrives weak and therefore tolerates less interference (i.e. smaller number of users in the cell). Figure 2 shows the interference boundary line for the system given before in (8) but with a larger cell radius of 2.5Km (other parameters of the system, services, propagation ...etc remain the same). In this case the service capacities of the two services have decreased to 140 for service class 1 and 52 for service class 2. The parameters $\alpha_{12}$ and $\alpha_{21}$ reflect the relative interference effect of one service user on the other service. They are dependent on parameters of the services and independent of the cell radius, as explained earlier in this section. Therefore, they remain the same as before, i.e. $\alpha_{12}=2.19$ and $\alpha_{21}=0.229$. In this case we write the boundary equations as:

\[
N_1 \leq 139.8 - 2.19 N_2 \\
N_2 \leq 52.0 - 0.229 N_1
\]  

(9)

4. Degradation of Service

The Degradation of Service parameter given in (2) will be analyzed for the case of system with capacity bounds given in Figure 1 with all weights set to 1,

\[
\text{DoS} = B_1 + B_2,
\]

(10)

$B_1$ and $B_2$ being the blocking rates for the services 1 and 2 respectively. Moving from one end of the boundary where only one service is allowed (with the other service blocking of 100% ) to the other end where the reverse occurs, the general topography of the DoS parameter given in (10) is explained using the contouring plot shown in Figure 3 for the case of a 1.5Km cell radius and traffic values of 30 Erlang for each of the two services. The contour lines show the variation in DoS level at and below the boundary.

The value of the DoS in this case corresponds to the expected service degradation for the restricted system; i.e. the system in which a predetermined point of
operation (number of users to be accepted in each service) is selected.

For ease of observation, we chose to have contour lines whereby the DoS level of any line to be double (or half) the level value of the DoS of the neighboring line. With any blocking value of convenience taken as a reference, blocking level variation is expressed in terms of units of Vd (Value doubled) with +1 Vd equivalent to doubling the blocking and -1 Vd equivalent to halving. Blocking B in percentage is converted to Vd units using the formula: \((10/3) \log_{10}(B/Bo)\) with reference made to a selected blocking value Bo. Therefore, a blocking increase of 2 Vd units (+2 Vd) means doubled twice (quadrupled) and -2 Vd means halved twice, and so on. Generally a Vd value of \(n\) means that value is (approximately) \(2^n\) times the reference value. In Figure 3 the reference of 0.01 (1%) was selected and contour lines are all spaced apart 1Vd unit. For this reference, absolute levels are expressed in Vd1% units (Value doubled reference to 1% blocking, and shortly we will use Vd1).

Investigation of contour lines plot in Figure 3 reveals the existence of working point with absolute DoS minimum value smaller than -2Vd1 (better than 0.25% blocking) occurring for \(N_1=50\) and \(N_2=46\). For any acceptable DoS working level other than the minimum there are two working points on the boundary satisfying this DoS level one of which allows more users of one service and less users of the other service and the other point does the opposite. This means flexibility in selecting the operating point on the boundary. For this same acceptable level other points of operation below the boundary on the corresponding contour level exist. Operating at any of these points is beneficial as level of interference out of the cell is reduced giving capacity (soft capacity to other cells).

Now we will investigate the DoS contour lines shown in Figure 4 plotted for the case of a larger cell radius of 2.5Km with traffic kept the same as before (30, 30 Erlang). Again we have a working point with absolute DoS minimum value. However, this new minimum has risen to some what less than +1Vd1 (better than 2% blocking) which corresponds to an increase from -2 to +1Vd (doubling three times). This new minimum occurs at \(N_1=50\) and \(N_2=42\).

To restore the acceptable DoS minimum level, numerical techniques were applied to find the appropriate traffic for a cell of this size (while keeping the proportionality between the traffic mix (in this example it was 1:1) and it was found to be \(A_1=A_2=26\) Erlang. Figure 5 shows the DoS contour lines plot for these traffic levels.

Of course, the reverse question of what the appropriate cell radius is for a given traffic mix and an acceptable DoS level. Apparently, for a two service case the answer can be obtained graphically using a
pre-laid contour lines for the given traffic mix and trying to fit the boundaries on it. For the more general case of more than two services a more complex numerical iteration technique is required.

Reverting to any of the previous contour plots again, it is noticeable that DoS contour lines become horizontal at operating points that allow increased numbers of users of service class 1 and vertical for service class 2. Horizontal contours means less sensitivity of DoS to changes of the operating point number of users of service 1 but a high sensitivity to the number of users of service 2 and vice versa for the vertical contours. It is important to take this into consideration and ensure that operating point is not driven to either direction because this will lead to delay in convergence to the target DoS. For the fully symmetric case, i.e. $A_1=A_2$ and $w_1=w_2$, all operating points with $N_1=N_2$ will have equal sensitivity of DoS changes with either traffic or operating point changes of both services. We will call the line formed by these points the path of convergence.

For the case in Figure 6, the contour lines plot for DoS corresponds to $A_1=34$ and $A_2=28$ Erlang ($w_1=w_2=1$) which is a non-symmetric case. The points of equal sensitivities forming the path of convergence in this case were obtained numerically. The path of convergence is approximated using these points by the straight line that is shown on the plot with its equation given by

$$N_2 = 0.9 N_1.$$  

The previous equation represents the optimum mixture of services in the cell to keep the operating point on the path of convergence. It is expected that increasing or decreasing the traffic while keeping their relative proportions intact will not affect the path of convergence, neither, the end target optimum point coordinates. However, the DoS level may change at this target point.

5. Discussion

WCDMA is interference limited system in which the capacity of any service at any time is not a fixed value and depends on the interference conditions in the network. Therefore, it is not a direct problem to calculate blocking rate for any service using Erlang B formula. In most cases traffic analysis was done for the single service case using the pole capacity, while the limiting on the power in the cell was not considered.

In this work we used a model for active user capacity boundaries that takes into consideration the power limitation on the uplink due to limitation on the mobile power and the propagation path. Using this model, the upper number of admissible connections is determined for any valid combination of numbers of users in other services for a given cell radius. Thereafter, for any operating point that is a feasible combination of numbers in the different services, blocking probabilities can now be calculated for each and every service using the Erlang B formula. An overall Degradation of Service, DoS, parameter that is a linear combination of the blocking probabilities of all services is defined.

For simplicity, we investigated the DoS that is simply the sum of all blockings. The behavior of this parameter is investigated for a mixture of two services to be able to make conclusions graphically. We plotted DoS contour lines for a given offered traffic mixture on and below the capacity boundaries for a certain cell radius, services and system parameters. We were able to conclude the following:

- An optimum (minimum) DoS value can be found some where on the system boundary.
- For any acceptable DoS level above the minimum the operating point can be shifted on the boundary in favor of one service or the other. This can be beneficial in cases where we have extra limits on blocking of one service or the other.
- The operating point can also be relaxed; i.e. working below the boundary. This can be beneficial in reducing interference generated and affecting other cells.
- The position of the operating point on the contour lines determines the DoS sensitivity to traffic variations and can be less sensitive to one service than the other.
• The path of convergence defines the set of operating points (the proper services mix) not biased to any service on the account of the other. Defining this path can be beneficial in determining on proper shift of operating point to lead to faster convergence to the optimum or target DoS in a traffic aware admission process.

6. Conclusions and Further Research

A measure for performance, DoS, that is a function of blocking rates of all services was introduced and linked to the complex feasibility problem in a multiservice environment on the uplink in WCDMA. DoS parameter is easily obtainable for a given traffic and system parameters and can be therefore used in the dimensioning and planning of WCDMA networks.

Admission control algorithms that optimize DoS parameter with a link to some QoS parameters may be suggested. Traffic analysis on the downlink in a multiservice case may be approached similarly.

7. References


