Traffic Control in a UMTS cell with static channels and traffic counts
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Abstract:
This paper describes & improvise Call Blocking Probability calculations, considering fixed number of channels & traffic generating sources in typical UMTS cell. More specifically, for uplink directions, a Loss Model (EnMLM) has been proposed by integrating it with local blocking aspects. As such the incoming call has to compete for the resources for it’s successful admission to a UMTS cell. In principle such admission of incoming call is controlled by availability of required channels. To analyze the system, an aggregate one-dimensional Markov chain has been formulated, and based on it, the system state probabilities have been determined by an efficient recurrent formula. Subsequently, the call blocking probabilities have been calculated in the uplink direction. By way of approach, the proposed model is approximate, however, its accuracy is found to be quite satisfactory. The evaluation of results has been done via simulation and results substantiate the findings of the basic call blocking probability calculations. Additionally, this model has much wider scope and it performs better than the existing model which assumes infinite number of traffic sources in the cell.

Keywords: WCDMA, Local blocking probability and Call blocking probability

INTRODUCTION

The evolution of wireless communication has been exponential since last two decades. This evolution is not only limited towards enhancement in technical aspects, but also in terms of increased customer expectation & more focus on QOE (Quality of Experience), rather than traditional QOS (Quality of Service).

Traditionally, the pre-existing second generation mobile networks like GSM were principally focused on voice and short message services, and a small thrust came in terms of GPRS at later stage, which can be termed as Era between 2.5G to 3G Transformation. In the third generation (3G) networks, user expects network access along with high data access speed, at, anywhere, anytime, and many additional features like Video Calls, multimedia applications, Improved Location based services, etc.

The substantial increase in subscribers and traffic demands naturally leads to high bandwidth consuming applications such as video streaming, online gaming, music downloading, high bandwidth eating applications like Facebook, Skype, Oovoo etc on Mobile fone etc. This requirement of high bandwidth is generally achieved through Universal Mobile Telecommunication system (UMTS) which operates with Wideband Code Division Multiple Access (WCDMA) over the air interface. UMTS provides a huge range of data services with bit rates up to 2Mbps and varying quality of service requirements.

UMTS is the yielded fruit of third generation of mobile communications technology for humanity, in which personal communications services like location independent, handset immune, one-to-one calling, with the choised means of transmission (wired or wireless) has been made available to mankind. Its purpose is:

- That users may be enabled to access a wide range of telecommunications services like multi-media and high data rates.
- To facilitate the low cost mobile handsets with higher battery backup & advanced applications.

UMTS uses Wideband Code Division Multiple Access radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators. There are two methodologies,
through which duplex operation usually take place -

- **Frequency Division Duplex (FDD)**
  This is primarily to give wide area mobile coverage in UMTS. It can support 384kb/s in a mobile environment and uses an independent 5Mhz frequency band for uplink and a separate 5Mhz for downlink.

- **Time Division Duplex (TDD)**
  TDD uses W-CDMA as the modulation scheme, same as in FDD, but shares a single 5Mhz channel for both uplink and downlink, while having separate time slots for both the uplink and downlink transmissions.

As the coverage area & capacity of a cell is limited, more so in case of medium or small sized cells, it is always more preferred to consider finite number of traffic resources, while analyzing the number of active users, attached with the cell.

In preliminary stage, there was a model in consideration, based on the principle of finite number of traffic resources. In this model, call blocking probability was being deduced based on reduced load approximation method, in uplink direction.

Then came the advanced & improvised model which is based on first Delbrouck’s algorithm and later on Poisson or quasi-random call arrival process to computes call blocking probability in bi-directional way i.e. both in the uplink and downlink route. However, these models doesn’t have a product form solution as the system was described by an irreversible Markov Chain.

In this paper, our research is based on Engset Multirate Loss Model (EnMLM) in order to carry out a precise calculation of call blocking probability in the uplink direction of a UMTS cell with fixed count of channels and traffic source. The total chip rate of 3.84 Mcps has been divided into a fixed number of channels where generally one channel is seized per call for conversation. To study the uplink system, an aggregate one-dimensional Markov chain is considered for clarity, where a state represents the total number of occupied channels in the cell. Based on this, call blocking probability is ascertained. Additionally, it is deduced that thus obtained call blocking probability of the projected model is much less than that of the corresponding model with infinite traffic count.

As evident, the result for uplink can also be applied for downlink direction calculations.

As such the accuracy of projected model could be verified through simulation.

**UMTS – A DEVELOPMENT FROM GSM & CDMA**

UMTS is built on top of the existing GSM infrastructure and integrates both circuit switching & packet switching. In other words it supports both packet and circuit data transmission. UMTS separates itself from GSM by using different frequency bands. With its fast transmission rates UMTS offers a wide additional range of multimedia services and parallel applications such as surfing the web, E-mail, while still talking on the phone, etc.

Apart from many differences between UMTS and GSM systems, there are some similarities also. Both systems are connected to the GSM core network for providing a radio connection to the handset. Hence, the technologies can share the same core network and based on the principles of a cellular radio system. Most of the individual elements of GSM are re-used in UMTS with require extensions (e.g. MSC, VLR etc.), but the UMTS Terrestrial Radio Access Network (UTRAN) elements are completely new. UMTS core networks must be able to interoperate both this new UTRAN and the existing GSM Base Station Subsystem (BSS) access network. In order to support more data intensive services, operators will need to upgrade capacity throughout their networks in order to cope with the expected increase in traffic, and use transport protocols which are more efficiently suited to data and
packet transport. Thus, in UMTS, generally Asynchronous Transfer Mode (ATM) is specified as the transport mechanism in the new interfaces in the radio access and between radio access and core network. The GSM Base Station Controller (BSC) corresponds to the WCDMA Radio Network Controller (RNC) of UMTS system. The GSM Radio Base Station (RBS) / BTS corresponds to the WCDMA RBS better known as Node B, and the A-interface of GSM was the basis of the development of the Iu-interface of WCDMA, which mainly differs in the inclusion of the new services offered by WCDMA. The GSM system uses TDMA (Time Division Multiple Access) technology with a lot of radio functionality based on managing the timeslots. The UMTS system on the other hand uses WCDMA, which means that both the hardware and the control functions are different. WCDMA is a multiple access technology where the users are separated by unique codes, which means that all users can use the same frequency and transmit at the same time. It uses a 5 MHz wide radio signal and a chip rate of 3.84 Mcps. Following are the main benefits of a wideband carrier with a higher chiprate:

- Support for higher bit rates
- Higher spectrum efficiency due to improved trunking efficiency and Higher QoS

Engset Multirate Loss Model (EnMLM)

In multi-rate networks, Call blocking probabilities (CBP) is a prime index to evaluate the quality of service.

In this scenario, CBP calculation is done where for each service class, call arrives from a identified finite source, by using different multi-rate loss models, and compete for the available or remaining bandwidth, as the situation may prevail in single link loss model. For e.g. a call may be rejected if no more link bandwidth is available at call-arrival time.

For the analysis of traditional networks with uncontrolled or randomly arriving calls, Erlang Multi-rate Loss Model (EMLM) is used, where calls are generated by infinite production of traffic sources. There calls from different service-classes arrive to a single link of certain bandwidth capacity according to a Poisson process, and compete for the available link bandwidth under the complete sharing policy. The EMLM has a product form solution that leads to an efficient and accurate calculation of CBP by using Kaufman and Roberts (K-R) recursion.

An important extension of the EMLM is the Engset Multirate Loss Model (EnMLM), where the call arrival process is considered quasi random - i.e. each service-class has finite population of traffic sources and gives the same results with the
Engset formula for the time congestion probability for a single service-class. The EnMLM has a Product Form Solution, whereas the CBP calculation in the EnMLM is hard to determine because enumeration and processing of the system state space are required. To avoid this and calculate the CBP efficiently in both uplink and/or downlink directions, Glabowski and Stasiak (G&S) method is used.

A Typical UMTS Model

Lets have an example of a typical UMTS Network consisting of a reference cell, along with some other neighboring cells. Lets further assume that the mobile users latched on to the reference cell, generate calls of $R$ different service-classes.

Maximum Number of Calls

The base station (BS) capacity in GSM is independent of the actual load of network because it is based on the number of available frequencies, however in case of a UMTS Network, the BS (Typically known as Node B), is interference limited. On the uplink the Multiple Access Interference (MAI) at a BS is caused by all mobile stations (MS) whether they belong to this BS or not. On the downlink the capacity is limited by the transmit power of the BS or by the interference it causes, respectively. The power control mechanisms in both link directions provide that the signals are transmitted with such powers that for each service they are received with nearly equal strength. Due to the universal frequency reuse in UMTS, all users both in the considered cell and in the neighboring cells contribute to the total interference, thus influencing the link quality in terms of received bit-energy-to-noise ratio ($E_b/N_0$).

The power control equation for service-class $r$ is written as follows:

$$\left(\frac{E_b}{N_0}\right)_r = PG \frac{RP_r}{(IP_{cell} - RP_r) + IP_{other} + NP}.$$  \hspace{1cm} (1)

where

- $E_b =$ Energy per bit
- $N_0 =$ Noise spectral density
- $PG =$ Processing Gain of service-class $r$ with activity factor $\delta_r$ and data rate $UR_r$

accommodated in the uplink of a UMTS cell of chip rate $CR = 3840$ kcps and represented as

$$PG = \frac{CR}{\delta_r UR_r}$$

$$RP_r =$ Received Power from a user to service class $r$.

$$IP_{cell} =$ Total received Interference Power from the user of the reference cell

$$IP_{other} =$ Total received Interference Power from the user of the other neighboring cells

$$NP =$ Background Noise Power

From (1) we obtain the value of $RP_r$ as
\[ R_P = \left( \frac{E_b}{N_0} \right)_r \left( \frac{IP_{cell} + IP_{other} + NP}{PG + \left( \frac{E_b}{N_0} \right)_r} \right) \]

\[ \text{Now, assume that only service-class } r \text{ contributes to } IP_{cell}, \text{ and contains maximum } N_r \text{ number of calls of service class } r \text{ in the cell. Thus we have } IP_{cell} = RP_r N_r. \text{ By putting this value in above equation, we get} \]

\[ IP_{cell} = \frac{N_r \left( \frac{E_b}{N_0} \right)_r \left( IP_{other} + NP \right)}{PG + \left( \frac{E_b}{N_0} \right)_r - N_r \left( \frac{E_b}{N_0} \right)_r} \]

\[ \text{Now, consider the Noise Rise, } NR, \text{ which is related to the uplink cell load, i.e } \beta_{ul} \]

\[ NR = \frac{TP}{NP} = \frac{IP_{cell} + IP_{other} + NP}{NP} = \frac{1}{1 - \beta_{ul}} \]

\[ \text{where } TP \text{ is the total interference power from the user of the reference & neighboring cells.} \]

\[ \text{To retrieve the value of } N_r, \text{ substitute (3) in (4)} \]

\[ N_r = \frac{pG + \left( \frac{E_b}{N_0} \right)_r}{\left( \frac{E_b}{N_0} \right)_r} \gamma (1 - \beta_{ul}) + \gamma \]

\[ \text{Channel Capacity and Bandwidth Requisition} \]

After calculating the maximum number of calls for each service-class, \( N_r \), we determine the system Capacity in channels by interpreting this number into channels for each service-class. First, we define the spread data rate of service-class \( r, DR_{s,r} \) as the proportion of \( W \) which is utilized by one call of service class \( r \).

\[ DR_{s,r} = \frac{W}{N_r} \]

\[ \text{To enumerate the relation between the uplink Capacity } C, \text{ and the bandwidth requirement per call of each service-class } r, B_r, \text{ it is necessary to set a basic bandwidth unit, } BW. \text{ For instance, we can use a } BW \text{ equal to 10 Kcps. Then} \]

\[ C = \left[ \frac{W}{BW} \right] = 384 \text{ channels} \quad \& \quad B_r = \left[ \frac{DR_{s,r}}{BW} \right] \text{ channels} \]

\[ \text{Where} \]

\[ i \text{ represents the total number of occupied channels i.e system state} \]

This is a simple and approximate way to convert the chip rate \( W \) and the spread date rate \( DR_{s,r} \) into channels. It is evident from equation no 7 that smaller the \( BW \) is, the smaller is the error introduced by this approximation.
Based on the preceding analysis, a recurrent formula for the call blocking probability can be derived as:

**Call Blocking Probability Computation**

In the case of Poisson arrival processes for the above hypothetical model, the K-R recursion computes the state probabilities, \( P(i) \), when the system is in state \( i \). The system state \( i (i = 0, \ldots, C) \) is defined as the total number of bandwidth unit occupied by the calls.

\[
P(i) = \frac{1}{i} \sum_{r=0}^{C} \varepsilon_r B_r P(i - B_r)
\]

\[\ldots\ldots (8)\]

where

\[\sum_{i=0}^{C} P(i) = 1\]

\[\varepsilon_r = \text{Offered traffic load of the service class } r\]

\[\text{i.e. } \frac{\theta_r}{\varphi_r} = \text{(mean arrival rate of } r) / \text{(mean service rate of } r)\]

However, in above equation, the probability of a fresh call to be blocked due to the effect of soft blocking is ignored in any system state \( i \). (The probability that a call is blocked when arriving at an instant with intra cell load, is called local blocking probability. As such, blocking occurs if the total interference exceeds a defined maximum level or if the cell load exceeds the maximum threshold. In such case Network admission control rejects the request for a new connection. The probability for this event, i.e. the blocking of a new call of service when arriving at an instance with own-cell load, is called local blocking probability.) Hence, this probability is referred as local blocking probability and subsequently above equation is modified to incorporate aspect of local blocking probabilities.

**State probabilities with local blocking probabilities for infinite number of sources**

We estimated the average number of channels, \( \bar{C} \), which are already being utilised due to the effect of local blocking with an independent, lognormal distributed random variable with following parameters

\[
\varphi = \frac{IP_{\text{other}} + NP}{IP_{\text{cell}} + IP_{\text{other}} + NP} \cdot \rho \cdot C
\]

\[\ldots\ldots (9)\]

where

\[\rho = \text{The average fraction of } C \text{ utilized by the in-service calls}\]

\[\tau = \frac{IP_{\text{other}}}{IP_{\text{cell}}}\]
The local blocking probability of a recently arriving call while the system is in state \( i \), is known as the state dependent blocking probability of service-class \( r \):

\[
I_{i,B_r} = IP (i' > C - (i + B_r - 1)) = 1 - CDF(C - (i + B_r - 1))
\]

\[\ldots\ldots(10)\]

where

\[
I = \text{Intra-cell interference}
\]

\[
CDF(x) = \text{The cumulative distribution function of the lognormal distribution.}
\]

Thus a new connection of service-class \( r \) with bandwidth requirement \( B_r \) is accepted only if the last requested channel is allocated successfully. We assume that the rest of the channels are already in occupied or allocated state.

The state probabilities computed in (8) can be customized to incorporate the state dependent blocking probabilities:

\[
P(i) = \frac{1}{i} \sum_{r=1}^{R} \varepsilon_r B_r (1 - I_{i-B_r,B_r}) P(i - B_r)
\]

\[\ldots\ldots(11)\]

In above equation, the factor \((1 - I_{i-B_r,B_r})\) actually reduces the arrival rate \( \vartheta_r \) from state \((i - B_r)\) to state \(i\).

**State probabilities with local blocking probabilities for finite number of sources**

So let's consider finite number of sources for each service-class. To find the state probability for finite number of sources within the cell, equation (10) need to be extended further. We presume that service-class' \( r \) calls derive from \( Y_r \) sources with a Poisson arrival process as it is derived in equation (8). Thus, we modify (8) to calculate the state probabilities:

\[
P(i) = \frac{1}{i} \sum_{r=1}^{R} (y_r(i) + 1) \varepsilon_r B_r P(i - B_r) \quad \text{for } i = 1 \ldots C , \sum_{i=1}^{C} P(i) = 1 , P(0) = 1
\]

\[\ldots\ldots(12)\]

where

\[
\varepsilon_r = \text{The offered traffic-load per idle source of service-class } r
\]

\[
i.e \quad \alpha_r \varphi_r^{-1}
\]

\[
y_r(i) = \text{The number of calls of service-class } r \text{ in state } i.
\]

Also equation (11) & (12) is used to compute the state probabilities as

\[
P(i) = \frac{1}{i} \sum_{r=1}^{R} (y_r(i) + 1) \varepsilon_r B_r (1 - I_{i-B_r,B_r}) P(i - B_r)
\]

\[\ldots\ldots(13)\]

In (12) and (13), the number of calls of each service-class \( r \), \( y_r(i) \), in different system states \( i \)
is approximated by the average number of service-class \( r \) calls, in state \( i \), assuming infinite number of sources for each service-class \( r \): 

\[
y_r(i) \approx \frac{\varepsilon_r P(i-B_r)(1-I_{i-B_r,B_r})}{P(i)}
\]

\[\cdots\cdots (14)\]

where \( \varepsilon_r \) and \( P(i) \) are the parameters of the corresponding infinite algorithm in (11).

**Call Blocking Probabilities**

Once the probability for each service class is determined, the call blocking probability can be easily calculated. The call blocking probability of each service-class \( r \) is computed by adding all the state probabilities multiplied with the state dependent blocking probabilities as follows:

\[
B_r = \sum_{i=0}^{C} P(i) I_{i,B_r}
\]

\[\cdots\cdots (15)\]

**Assessment And tangible result**

Here we analyze the analytical versus the simulation results for the call blocking probability. We evaluate the accuracy of both the infinite and finite algorithms which we discussed above. For this we present a case study.

Consider an uplink with \( \beta_{ul} = 0.65, \tau = 0.5 \) and \( \gamma = 2 \). Also consider three service-classes with following parameters:

<table>
<thead>
<tr>
<th>Service Class</th>
<th>DR</th>
<th>( \delta )</th>
<th>( E_b/N_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.2 Kbps</td>
<td>0.67</td>
<td>3 DB</td>
</tr>
<tr>
<td>2</td>
<td>144 Kbps</td>
<td>1.0</td>
<td>2.5 DB</td>
</tr>
<tr>
<td>3</td>
<td>384 Kbps</td>
<td>1.0</td>
<td>2 DB</td>
</tr>
</tbody>
</table>

A comparison between analytical versus simulation call blocking probability results which are the mean values from 6 runs with confidence interval of 95% is made. The resultant reliability ranges of the measurements are small enough and therefore we present only the mean call blocking probability results.

Figure shows call blocking probability for different number of sources of each service-class that generate traffic.

The ratio of the number of sources at the x-axis is kept constant and equal to 2:1:1 while the INF-
point represents the case with infinite number of sources. The offered traffic load is constant for each service-class and equal to \( \varepsilon_r = \gamma_r \varepsilon_r' \). We consider a case where \( \varepsilon_1 = 15 \text{ erl} \), \( \varepsilon_2 = 8 \text{ erl} \), \( \varepsilon_3 = 4 \text{ erl} \). The model’s accuracy is satisfactory for every case of the number of sources. We also observe that decreasing the number of sources, the call blocking probability also drop thus showing the overestimation that is made by considering the infinite model.

**CONCLUSION**

A new model for the cell-level analysis is been presented here for a UMTS cell with finite number of resources & fixed quantity of channels. Based on chip rate of UMTS carrier, firstly the channel capacity of system is determined, for each service-class. Afterwards the K-R recursion is modified to include local blocking aspects, and subsequently local blocking to EnMLM has been accumulated. In later scenario, relevant EMLM is used to calculate system state blocking probability, and the formula for calculation of CBP thus obtained is counter-verified through simulation results. The application examples substantiate the significance & necessity of the new designed model, because in new model the CBP is very much reduced for finite & infinite traffic sources, as compared to traditional model, and the accuracy of new model is validated through parallel simulation results.

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