Downlink Capacity of Mixed Traffic in WCDMA Mobile Internet

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Abstract

Calculation methods for capacity analysis in WCDMA systems by hand-calculator and/or by personal computer are needed for mobile cellular engineers for preliminary design purposes, and/or for quick evaluation purposes. The scope of this paper is to outline how to calculate the capacity of the WCDMA radio access network. Specifically, the paper analyzes the capacity of WCDMA downlink in mixed speech/packet traffic. The procedure in this paper adopts the simplest and most accurate models from many research works to construct the simplest procedure for analyzing WCDMA downlink capacity. The methods described in this research can be used for rough estimates suitable in the dimensioning process and will be a valuable contribution towards mobile Internet system designs.

Keywords: WCDMA, Capacity, Downlink, Mixed Traffic, and Mobile Internet.

1. Introduction

The WCDMA (UMTS/IMT-2000), third Generation (3G) technology, is intended to revolutionize the capabilities of mobile communications. The 3G systems are expected to integrate all present and future services into one system. The current WCDMA specification fully satisfies the IMT-2000 requirements, including support data rates up to 2 Mbps in indoor and small-cell-outdoor environments and up 384kbps with wide-area coverage, as well as support for both high-rate packet data and high-rate circuit-switched data. These data rates are acceptable for many Internet based applications. The goal is to support a large variety of services, most of which are not known yet, over a large variety of radio conditions. It must be able to cope with variable, asymmetric data rates with different quality of service requirements. The main application for the high-rate data services will be wireless packet transfer, e.g., for wireless access to the Internet. However, UMTS will also support high-rate circuit-switched services such as video [1].

UMTS terrestrial radio access (UTRA) includes both a frequency-division duplex (FDD) mode and time-division duplex (TDD) mode. The FDD mode is based on pure WCDMA while the TDD mode includes an additional time-division multiple-access (TDMA) component according to the TD/CDMA proposal. The TDD mode is considered to be a complement to WCDMA to boost the capacity in local areas. It should be noticed that WCDMA TDD is mainly used for indoor coverage.
In conventional voice communications, the traffic volumes of uplink and downlink are similar to each other usually. However, the 3G cellular systems will provide wireless multimedia services where the utilization of radio resource is strongly biased toward the downlink against the uplink. For example, let us consider Internet access or mobile computing. Short commands are transmitted via downlink. Internet access is unidirectional; the downstream data will be more than 6 times of the upstream data. In fact, the problem caused by traffic unbalance between uplink and downlink is inherent in any FDD system.

Basically, the WCDMA downlink air interface capacity is shown to be less than uplink capacity. The main reason is that better receiver techniques can be used in the base station than in the mobile station. These techniques include receiver antenna diversity and multi-user detection. Additionally, in UMTS, the downlink capacity is expected to be more important than the uplink capacity because of asymmetric downloading type of traffic [2], [3].

Technically, the downlink analysis is more complex than the uplink one. For the downlink, it is not as easy to separate the coverage and capacity in the way as that is done for the uplink [2]. The main difference as compared to the uplink is that the user equipments (UEs) in the downlink share one common power source. Thus the cell range is not dependent only on how many UEs there are in the cell but also on the geographical distribution of the UEs. In downlink analysis, each user will experience a different interference level; it is not possible to use a single interference level that is valid for all subscribers in the same way as is done for the uplink. Instead more complex approaches must be used. In this reason, the solution is to rely on simulations to estimate what capacity the system would be able to support at a given range [2]. Therefore, many researchers are in search of simple methods, which are at the same time and sufficient to explain the physical aspects of the downlink traffic, precisely.

The scope of this paper is to outline how to calculate the mixed-traffic downlink capacity of the WCDMA radio access network. Specifically, the maximum number of simultaneous users of downlink is calculated for speech users at vehicular speed 3km/hr. For data/packet traffic, the maximum download capacity in Mbyte/cell/hr is calculated. The procedure in this paper adopts the simplest and most accurate models from many standard research works to construct the simple procedure for WCDMA capacity analysis. The methods described can be used for rough estimates suitable in the dimensioning process. Note that by capacity is meant the maximum number of simultaneous users that a cell can support.

2. WCDMA TRAFFIC

Traffic refers to the usage of channels and is usually thought of as the holding time per time unit (or the number of “call hours” per hour) for one or several circuits (trunks or channels). Traffic is measured in Erlangs (E). For example, if one subscriber is holding on the telephone, this would generate one call hour per hour or 1 E of traffic. The level of traffic per one cell depends on the number of traffic channels available and the amount of congestion that is acceptable, the so-called Grade of Service (GoS).

In traditional speech, only services traffic dimensioning is based on the Erlang-B calculations. Well-known Erlang’s B-table is the standard table that can be used to calculate the level of traffic based on the most common assumptions used. These assumptions are:

(1) No queuing condition in the system.
(2) Number of subscribers much higher than number of traffic channels available.
(3) No dedicated (reserved) traffic channels.
(4) Poisson distributed (random) traffic is assumed
(5) Blocked calls abandon the call attempt immediately
Erlang’s B-table relates to the number of traffic channels, the GoS, and the traffic offered.
From an end-user and application point of view four major traffic classes can be identified within the two application groups [4]:

Real-time applications
- Streaming class, where the fundamental characteristics for QoS are to preserve the time relation (variation) between information entities of the stream.
- Conversational class, where the fundamental characteristics of QoS are to preserve time relation (variation) between information entities of the stream and to have a low delay

Non-real time applications
- Background class, where the destination is not expecting the data within a certain time but with preserved payload content.
- Interactive class, where a request/response pattern is of importance and the payload content must be preserved. Conversational and streaming classes are intended to carry realtime traffic flows, like speech and video streaming. Interactive class and background class are used by traditional Internet applications such as WWW and e-mail.

In a WCDMA network this process becomes quite complex. The following three types of services can be supported in a cell: voice, circuit switched data and packet switched data services. The different service types must be treated differently as they are carrying different applications.

Voice and circuit switched data services require allocation of fixed rate resources to provide the actual service while packet switched traffic can utilize the remaining resources efficiently due to its elastic nature.

In multi-service networks several services with different parameters share the same resource. The inputs of multi-service cell dimensioning are the offered load, the required resource (effective bandwidth), the requirements on blocking for each service and the total resource available in the cell. For a given number of subscribers the blocking probabilities are different for different services because they share the same pool of resources. The more resources a service needs for one user the higher is the blocking probability.

Voice and circuit switched services should be handled in the way described above but for packet switched services this leads to over dimensioning.

In packet switched applications the minimum average throughput can be taken as dimensioning criterion. The part of the resource, which is not used for circuit switched services, can be utilized by packet services. For example, if the number of users is 133, the channel utilization becomes 16%. That means that on average 84% of the resources are available for best-effort services.

Best effort means that the packet service can utilize the resource that is available, but there are no guarantees on “blocking probabilities”, delays or throughput.

The main objective for the 3G systems has been high-bit-rate services for mobile users. Basically the 3G systems should be able to offer at least 144kbps (preferably 384kbps) for mobility users with wide-area coverage and 2Mbps for low-mobility users with local coverage.
In this paper, the mixed traffic, 12.2kbps speech-traffic and 128kbps packet-traffic, is chosen for the study. The level of traffic per subscriber for 12.2kbps speech-traffic and 128kbps packet-traffic is shown in Table 1. Table 1 will be used to calculate maximum capacity in the next section.

### Table 1 Traffic per subscriber for downlink

<table>
<thead>
<tr>
<th>Traffic type</th>
<th>Traffic per subscriber</th>
<th>Activity factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech 12.2 kbps</td>
<td>25mErlang</td>
<td>50%</td>
</tr>
<tr>
<td>Packet 128 kbps</td>
<td>250 kbyte/hr</td>
<td>Best Effort</td>
</tr>
</tbody>
</table>

### 3. DOWNLINK CAPACITY OF WCDMA: MIXED TRAFFIC

\( M_{\text{max}} \) is the maximum number of simultaneous users supported by a single cell-carrier at 100% loading in an evenly loaded system assuming that all users are using a single service. Table 2 shows the \( M_{\text{max}} \) values of the downlink for a three-sector site configuration.

### Table 2 Typical downlink \( M_{\text{max}} \) values at 100% load for a three-sector site configuration.

<table>
<thead>
<tr>
<th>Service</th>
<th>( M_{\text{max}} ) Three-sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech 12.2 kbps</td>
<td>120</td>
</tr>
<tr>
<td>Circuit Switch 64 kbps</td>
<td>15</td>
</tr>
<tr>
<td>Packet Switch 128 kbps</td>
<td>11</td>
</tr>
</tbody>
</table>

Normally, the downlink analysis is more complex than the uplink one. Since each user will experience a different interference level, it is not possible to use a single interference level that is valid for all subscribers in the same way as is done for the uplink. Instead more complex approaches must be used [2]. For dimensioning purposes, the current solution is to rely on simulations. A set of different simulations with varying traffic loads, ranges and path loss has been performed in order to estimate what capacity the system would be able to support at a given range as shown in Fig. 1.

![Fig. 1 Simulation results of capacity versus cell range in an urban environment. Each curve corresponds to a certain downlink margin (DL\(_{\text{marg}}\)) [2], [5].](image)

A downlink link budget is obtained by determining \( DL_{\text{marg}} \) according to the following equation [6]. All units are in dB:

\[
DL_{\text{marg}} = BL + CPL + BPL + \Delta G_{\text{ant}} + L_{f+j} + L_{\text{slant}} + L_{\text{TMA}} + \Delta N_f + \Delta A_0
\]

where:

- \( BL \) is the body loss, 0 or 3 dB.
- Note: Generally, body loss is not applied for data services since the users will most likely not have the terminal by the ear.
- \( CPL \) is the car penetration loss, 6 dB.
- Note: When a UE is placed in a car without external antenna, an extra margin has to be added in order to cope with the penetration loss to reach inside the car. This extra margin is approximately 6 dB.
All parameters in Table 3 are used to calculate the $DL_{marg}$ for the speech traffic by substitute them to Eq. (6). The result is $DL_{marg} = 25.2$ dB (indoor). However, if the mobile user changes the environment to the urban outdoor-pedestrian environment ($BPL = 0$), the result of $DL_{marg}$ will be 7.2 dB.

The values in Table 3 correspond to 100% system load. Basically, to secure a well performing network the downlink load used in the dimensioning process should be of the order of 50-75% depending on the implementation of radio network functionalities [6]. In practice, the number of simultaneous packet/data users (internet users) in an urban environment is calculated at a range of 1.5 km.

### 3.1 Mixed Traffic with a single attenuation level

Table 2 shows the $M_{max}$ values of the downlink. Now, the downlink capacity of a three-sector site at maximum loading can be calculated.

This example shows how to calculate the number of simultaneous users per cell for the 12.2kbps speech-traffic for the indoor environment:

1. In Fig. 1, the relative load at which the curve for $DL_{marg} = 25.2$ dB crosses the 1.5 km range is found approximately about 60%.
2. The $M_{max}$ value for speech 12.2 kbps for three-sector is found in Table 2 whis is 120.
3. The supported relative load is calculated: $0.6x120 \approx 72$ channels. Now, refer to Erlang table, 72-channel traffic (assuming a GoS of 2%) is equivalent to 61.04E.
4. Finally, the number of simultaneous speech-users can be calculated: $61.04/0.025 = 2441.6$.

Thus, in this specific case, one cell would be able to support approximately 2441 simultaneous users at the 12.2kbps speech-
traffic. However, the Radio Base Station (RBS) can provide more than one carrier per cell. For the example, if the RBS provides up to 4 carriers per call, the total simultaneous users will be 2441×4 = 9764 users per cell.

Next, the downlink best effort of packet traffic is calculated. This example shows how to calculate the amount of data per cell for the 384 kbps packet-traffic:

(1) Technically, one sector can support 26.3E with 35 channels (GoS of 2%), hence the served traffic is 26.3E×0.98 = 25.77E.

(2) The load available for packet traffic is 0.6–25.77/120 = 0.39.

(3) Hence, the downlink can support: 0.39×4×128×3600/8 = 89.86 Mbyte/sector/hr.

### 3.2 Mixed Traffic with a different attenuation level

In practice, each user will experience a different attenuation level; it is not possible to use a single attenuation level that is valid for all subscribers. A common situation is that services experience different path loss ($DL_{marg}$). For instance, it may be required to dimension a network where a fraction of the users are located indoor. In this case, the downlink margin is calculated according to [2], [7]:

$$DL_{marg} = 10\log\left[p_1 \times \frac{DL_{marg,1}}{10} + p_2 \times \frac{DL_{marg,2}}{10} + \ldots\right]$$  \hspace{1cm} (7)

where

- $DL_{marg,n}$ is the downlink margin of service $n$
- $p_n$ is the percentage using service $n$

Generally, body loss (BL) is not applied for data services since the users will most likely not have the terminal by the ear.

The level of attenuation for each type of traffic is shown in Table 4. The values in the Table 4 will be used to calculate $DL_{marg}$ in each case as shown in Table 5.

#### Table 4 Margin factors for various environment

<table>
<thead>
<tr>
<th>Factor</th>
<th>Speech (outdoor)</th>
<th>Speech (indoor)</th>
<th>Packet (vehicle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL</td>
<td>3 dB</td>
<td>3 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>CPL</td>
<td>0 dB</td>
<td>0 dB</td>
<td>6 dB</td>
</tr>
<tr>
<td>BPL</td>
<td>0 dB</td>
<td>18 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>$G_{ant}$</td>
<td>18 dBi</td>
<td>18 dBi</td>
<td>18 dBi</td>
</tr>
<tr>
<td>$L_{f+I}$</td>
<td>5 dB</td>
<td>5 dB</td>
<td>5 dB</td>
</tr>
<tr>
<td>$L_{slant}$</td>
<td>1 dB</td>
<td>1 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>$L_{TMA}$</td>
<td>0.4 dB</td>
<td>0.4 dB</td>
<td>0.4 dB</td>
</tr>
<tr>
<td>$N_f$</td>
<td>7 dB</td>
<td>7 dB</td>
<td>7 dB</td>
</tr>
<tr>
<td>Ant. Height</td>
<td>40 m</td>
<td>40 m</td>
<td>40 m</td>
</tr>
</tbody>
</table>

#### Table 5 $DL_{marg}$ for three types of traffic

<table>
<thead>
<tr>
<th>Traffic type</th>
<th>$p_n$</th>
<th>$DL_{marg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech 12.2 kbps (outdoor)</td>
<td>0.4</td>
<td>7.2 dB</td>
</tr>
<tr>
<td>Speech 12.2 kbps (indoor)</td>
<td>0.4</td>
<td>25.2 dB</td>
</tr>
<tr>
<td>Packet 128 kbps (in vehicle)</td>
<td>0.2</td>
<td>10.2 dB</td>
</tr>
</tbody>
</table>

After calculating the $DL_{marg}$ in Eq. (7) by using the values in Table 5, the result is $DL_{marg} = 21.36$ dB. Now, the downlink capacity can be calculated. Following the procedure in both speech and packet/data cases above, the number of simultaneous users in each type of traffic can be calculated. The results show in Table 6.

In Fig. 1, the relative load at which the curve for $DL_{marg} = 21.36$ dB crosses the 1.5
km range is found approximately about 50%. Finally, the number of simultaneous speech users and data/packet users can be calculated. The results show in Table 6.

Table 6 Capacity of speech users and data/packet users

<table>
<thead>
<tr>
<th>Traffic type</th>
<th>Capacity (4 carriers/cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech 12.2 kbps (outdoor)</td>
<td>3970 users/cell</td>
</tr>
<tr>
<td>Speech 12.2 kbps (indoor)</td>
<td>3970 users/cell</td>
</tr>
<tr>
<td>Packet 128 kbps (in vehicle)</td>
<td>197 Mbyte/sector/hr</td>
</tr>
</tbody>
</table>

4. Conclusions

This paper outlines how to calculate the capacity of the WCDMA mobile Internet network. The paper analyzes the capacity of WCDMA downlink in term of the number of simultaneous users per one cell. The maximum number of simultaneous users of downlink is calculated for speech users at vehicular speed 3km/hr. For data/packet traffic, the maximum download capacity in Mbyte/cell/hr is calculated. The research contributes to the quick and simple procedure of mixed-traffic analysis in WCDMA downlink. The methods described in this paper can be used for rough estimates suitable in the dimensioning process and offers a quick analysis for mobile cellular engineers.

References


