

**ESG**

*Engineering Services Group*

***Air Interface Cell Capacity of WCDMA  
Systems***

***80-W0989-1***

***Revision A***

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# 1 Introduction

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Significant increases in wireless subscribers and traffic, with new bandwidth consuming applications such as gaming, music downloads and video streaming have placed new and high demands of RF capacity on UMTS network operators. To handle this fast increasing capacity demands, the wireless network operators need to augment the network capacity frequently, sometimes even from the very start of the network deployment. In particular, proper capacity design of the radio access part of the wireless network, also known as RAN, is considered to be of essential importance as the radio resource is often the most expensive part of the network, while meeting the quality of service (QoS) requirements of the mobile services in the targeted coverage. At the same time, the network deployment costs to meet these requirements must be kept at the lowest possible level. Therefore the task of RF capacity planning is challenging indeed as overprovisioning results in waste of RF resources while underprovisioning would degrade quality of service.

To determine the capacity of a WCDMA RAN, it is essential to understand the capacity of a single WCDMA cell, which is also referred to as the WCDMA *cell capacity*. It is normally defined as maximum amount of communication traffic (in terms of bits) or services (in terms of number of simultaneous calls or sessions) that can be supported by the cell, while a more understandable voice capacity is referred to in Erlangs.

One question that is often asked by an operator when planning a WCDMA network is at a minimum “what is the average cell capacity (in my network)?” Strictly speaking, the answer to this question, even if only one type of service (voice, circuit switched data or packet data) is assumed, is not a single number since it depends on various factors, such as, the coverage, the quality of service target, the application or the mix of applications that the subscribers use on the underlying data connection, the network configuration, the morphology (the radio propagation characteristics), and the mobility environment considered, etc. For each individual deployment environment, the question can only be answered by actual drive tests after the detailed network planning exercise. However, estimations of the cell capacity can still be obtained using capacity analyses to provide operators as guidelines to make strategic decisions in deploying a WCDMA network.

This paper outlines the simple WCDMA cell capacity estimations by showing the WCDMA cell capacity as a function of the mobility channel and user traffic mix. The cell capacities on both uplink and downlink for Release-99 are discussed first. Then, the cell capacity for Release-5 is shown. To provide a more complete picture of capacity planning, a discussion on capacity versus coverage is also given. The WCDMA capacity is always considered as a 3 dimensional problem with trade-offs between coverage and quality of service

Four different mobility channels are considered in this paper: AWGN, or static channel, and the three mobility cases given in Table 1.

Table 1 Mobility Channels for Capacity Estimation<sup>1</sup>

	Case 1, speed 3km/hr		Case 2, speed 3 km/hr,		Case 3, speed 120 km/hr	
	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]	Relative Delay [ns]	Relative mean Power [dB]
1 <sup>st</sup> detected path	0	0	0	0	0	0
2 <sup>nd</sup> detected path	976	-10	976	0	260	-3
3 <sup>rd</sup> detected path	NA	NA	20000	0	521	-6
4 <sup>th</sup> detected path	NA	NA	NA	NA	781	-9

The user traffic considered in this paper is of the following three types.

- Speech: circuit-switched symmetrical service (radio bearer 12.2 kbps UL/DL).
- Circuit Data: circuit-switched (CS) symmetrical service (64 kbps UL/DL). Circuit-switched data applications could be video telephony, video streaming, etc.
- Packet Data: packet switched (PS) asymmetrical service (64 kbps UL/64, 144, 384 kbps DL). Packet switched data applications can be FTP, WWW, or others.

## 2 Release-99 Cell Capacity

To support calls in Release-99 systems, the RAN normally assigns dedicated physical channels (DPCH) for each call to carry the traffic<sup>2</sup>. Hence, as an approximation, the cell capacity can be defined by the maximum simultaneous DPCHs assigned within a WCDMA cell. On each dedicated channel, the coding and modulation (hence the data rate  $R_b$ ) is fixed. The power on the DPCH, however, is power controlled to handle the radio channel variations. As the radio channel condition changes, the RAN adjusts the transmit power on each DPCH to maintain a (constant) target signal-to-noise ratio  $E_b/N_t$  (the energy per bit to total noise spectrum density ratio) in order to achieve the desired QoS.

The target  $E_b/N_t$  value plays an important role in determining the WCDMA cell capacity. On the downlink, the higher the target  $E_b/N_t$ , the higher the (average) traffic channel power needed per

<sup>1</sup> The mobility power delay profiles specified in the table are from the 3GPP specifications TS 25.101.

<sup>2</sup> The FACH operation in Release 99 system does allow data users to communicate without a dedicated physical channel, instead, on a common physical channel. For the simplicity of the analysis, however, the FACH operation related capacity investigation is not covered in this paper since the majority of the traffic in the WCDMA network is carried by dedicated traffic channels.

DPCH, resulting in less total number of simultaneous DPCHs that can be assigned since the total cell transmission power is limited. On the uplink, the high target  $E_b/N_t$  requires high transmission power on the DPCH and high interference at the node-B receiver since, in WCDMA, for each user, the other users' signals are interference.

Besides the  $E_b/N_t$ , the data rate  $R_b$  also affects the cell capacity. High data rates require high transmission power and causing high interference, resulting in lower number of simultaneous DPCHs.

The target  $E_b/N_t$  is mostly a function of the mobility channel and QoS requirement, while the data rate  $R_b$  is mostly a function of the applications that the underlying data channel uses it for. Therefore, the WCDMA cell capacity is a function of the mobility channel, the type of application, and the corresponding QoS requirement. As illustrated in the following subsections, by determining the basic relationship between the cell capacity and target  $E_b/N_t$  with data rate  $R_b$ , one can derive the cell capacity numbers with respect to different mobility channels and QoS requirements.

## 2.1 Uplink Capacity

Consider a cell in a WCDMA network, the upper bound of the uplink capacity, referred to as the pole capacity ( $N_{pole}$ ) of a WCDMA carrier, can be estimated using the standard uplink capacity equation. This widely-accepted formula (Equation 1) is derived from the early CDMA literature and applies equally to WCDMA if variables are set properly.

$$N_{pole} = \frac{W/R_b}{E_b/N_t * v * (1 + \alpha)} \quad \text{[Equation 2]}$$

- **W**: the spreading bandwidth of the system, fixed by the standard at 3.84 mega Hertz (MHz)
- **R<sub>b</sub>**: the radio access bearer bit rate (bits per second) for the selected application
- **E<sub>b</sub>/N<sub>t</sub>**: the energy per bit to total noise spectrum density ratio
- **v**: the voice activity factor: The voice activity factor depends on the type of vocoder used, channel coding, and the actual application.
- **α**: the interference factor: It is the ratio between the other cell interference power and the total received signal power of users in the cell. The interference factor depends mainly on the quality of network planning, because it represents other-cell interference.

In addition to the target  $E_b/N_t$  and data rate  $R_b$ , Equation 3 shows that the uplink cell capacity is also a function of the voice activity factor  $v$  and the interference factor  $\alpha$ . For the initial capacity estimation, the voice activity factor is normally set to 0.6, and the interference factor is normally set to 0.6.

The pole capacity is obtained by assuming that each mobile or user equipment (UE) has infinite transmission power and the interference at the node-B receiver goes to infinity. For a practical system, both UE transmission power and the node-B receiver allowed interference level are

limited and the operating point is set well below the pole capacity. This operating point is referred to as the uplink loading and is defined as the percentage of the pole capacity. From the pole capacity, a practical cell capacity ( $N_{user,\eta}$ ) for a system can be calculated after the uplink loading ( $\eta$ ) has been determined, as shown in Equation 4

$$N_{user} = N_{pole} * \eta \quad \text{[Equation 5]}$$

### 2.1.1 Voice Capacity

The UMTS voice service is carried by a symmetric radio channel of data rate  $R_b$  at 12.2 kbps. Based on the minimum performance requirements specified by UMTS Release-99, the maximum uplink target  $E_b/N_t$  for different mobility channels is shown in Table 2.

Assuming the operating point  $\eta = 75\%$  and  $60\%$ , the uplink cell capacity for voice service under different mobility channel conditions can be estimated using Equation 6 and Equation 7. The result is shown in Table 2.

Table 2 : Uplink Cell Capacity for Voice Service  
(in terms of number of simultaneous voice calls)

	AWGN	Case 1	Case 2	Case 3	Target BLER
Target $E_b/N_t$	5.1 dB	11.9 dB	9 dB	7.2 dB	1 %
Pole Capacity	101	21	41	62	
75% Loading Capacity	76	16	31	47	
60% Loading Capacity	60	12	24	37	

The result is a bit pessimistic (especially for the mobility cases) since the capacity estimation is based on the maximum  $E_b/N_t$  value. In practice, the target  $E_b/N_t$  values depend on the actual baseband signal processing implementation of different vendors and could be lower than that are shown in Table 2. Hence, the actual uplink voice capacity could be higher than the number presented in the table. As an example, considering a 0.5 dB improvement in target  $E_b/N_t$  the voice capacity gain would be 10 to 12%, depending on the case considered. Similarly, a 10% improvement in lowering the interference (hence the interference factor  $\alpha$ ) would also translate into ~ 10 % gain in capacity. In other words, the numbers in Table 2 could serve as a lower bound of the cell pole capacity for normal practical systems.

What is also apparent from Table 2 is that when dimensioning a network selecting the proper channel model would be critical. When simulation are performed with a mixed channel conditions, corresponding to a typical distribution found in an urban environment, the cell capacity of 55 to 60 channels per cell can be supported.

### 2.1.2 Circuit Switched Data Capacity

The pole capacity can still be computed using Equation 8 for circuit switched (CS) data. However, the voice activity factor  $v$  should be changed to the activity factor of the circuit switched data. Consider the CS application video telephony with the data rate 64 kbps, the activity factor is assumed to be 1 (i.e. 100% active). The corresponding pole capacity can be

obtained given the maximum target  $E_b/N_t$  values specified in the UMTS Release-99 minimum performance requirements and the interference factor of 0.6. The result is presented in Table 3.

Table 3 : Uplink Cell Capacity for Video-Telephony  
(in terms of number of simultaneous CS calls)

	AWGN	Case 1	Case 2	Case 3	Target BLER
Target $E_b/N_t^3$	1.7 dB	9.2 dB	6.4 dB	3.8 dB	1 %
Pole Capacity	25	5	9	16	
75% Loading Capacity	19	3	6	12	
60% Loading Capacity	15	3	5	9	

Again, the numbers presented in the table could be served as the lower bound of the cell pole capacity for video telephony for practical systems.

### 2.1.3 Packet Switched Data Capacity

For the packet switched (PS) data with data rate 64 kbps, the pole capacity and the capacities at 75% and 60% loadings are given in Table 4. Here, the activity factor is assumed to be 1, in order to calculate the cell throughput irrespective of application, and the interference factor is 0.6. Also, the BLER is set to 10% for a typical packet switched data application. The higher BLER setting possible is because packet losses due to high BLER can be recovered by upper layer (such as radio link control, RLC, layer) retransmission at the expense of increased packet delivery latency. For some data applications, such as FTP file upload, this increased latency is tolerable.

Table 4 : Uplink Cell Capacity and Throughput for PS 64 kbps

	AWGN	Case 1	Case 2	Case 3	Target BLER
Target $E_b/N_t$	1.5 dB	6.2 dB	4.3 dB	3.4 dB	10 %
Pole Capacity	27	9	14	17	
75% Loading Capacity	20	7	10	13	
60% Loading Capacity	16	5	8	10	
Pole Throughput	1.7 Mbps	0.6 Mbps	0.9 Mbps	1.1 Mbps	
75% Loading Throughput	1.3 Mbps	0.4 Mbps	0.7 Mbps	0.8 Mbps	
60% Loading Throughput	1.0 Mbps	0.3 Mbps	0.5 Mbps	0.7 Mbps	

Different from the voice and circuit switched data, the cell capacity for packet switch data is normally measured in terms of the aggregated cell data throughput instead of the number of

<sup>3</sup> The target  $E_b/N_t$  values are obtained from the 3GPP specification TS 25.101.

simultaneous calls. This is because the packet data traffic is bursty and delay insensitive. Hence, it is possible to have multiple PS users/calls share a single DPCH. The uplink cell throughputs with respect to the pole capacity and 75% and 60% loadings are also presented in Table 6.

## 2.2 Downlink Capacity

In the downlink as well, the pole capacity can be interpreted as the maximum capacity with infinite BTS power. The down link pole capacity is not easy to analyze, but can be (approximately) simulated by keeping a very small cell radius (close to zero coverage) and the capacity reaches a limit in the trade-off between coverage and capacity.

A closed-form equation can also be derived for the downlink pole capacity by simplifying certain assumptions (Equation 9).

$$N_{pole} = \frac{(1 - \eta_{OH}) * W / R_b}{E_b / N_t * V * \left( \delta + I_{oc} / \hat{I}_{or} \right)} \quad \text{[Equation 10]}$$

- $\eta_{OH}$ : the percentage of the overhead channel power: For a practical network, the overhead channel power can largely affect the coverage of the WCDMA cell.
- $I_{oc}$ : the total interference power at the UE receiver
- $\hat{I}_{or}$ : the total downlink cell transmission power at the UE receiver
- $I_{oc} / \hat{I}_{or}$ : the interference factor: It is the ratio between the other cell interference and the total signal power from the cell. The interference factor depends mainly on the quality of network planning, because it represents other-cell interference. Note the value is normally not the same as that of the uplink interference factor  $\alpha$ . The inverse value  $\hat{I}_{or} / I_{oc}$  is also referred to as the *cell geometry*.
- $\delta$ : the orthogonality factor: It is the percentage of the serving-cell signal that becomes the interference at the UE receiver due to the multipath effect and the limitations of the rake receiver.

The downlink interference factor (or the geometry) is a location dependent value for each user in the cell. For locations close to the cell transmission antenna, the interference factor is very low (i.e., high geometry), while for locations close to the cell edge, the interference factor will be high (i.e., low geometry). For the purpose of capacity estimation, a medium value should be used.

In practices, since the downlink transmission power cannot be infinity and the cell radius cannot be zero, instead of using the pole capacity equation, the downlink capacity is normally evaluated using Equation 11.

$$N_{user,downlink} = \frac{I_{or} * (1 - \eta_{OH})}{\nu * E_{c,DPCH}} = \frac{(1 - \eta_{OH})}{\nu * E_{c,DPCH} / I_{or}} \quad \text{[Equation 11]}$$

- **E<sub>c,DPCH</sub>**: the expected transmission power on the DPCH
- **I<sub>or</sub>**: the total downlink cell transmission power

The expected DPCH power, E<sub>c,DPCH</sub>, depends on the target E<sub>b</sub>/N<sub>t</sub> and the power control margin, hence the mobility channel, as well as the target BLER.

### 2.2.1 Voice Capacity

Based on the minimum performance requirements specified by UMTS Release-99, the maximum downlink target E<sub>b</sub>/N<sub>t</sub> for different mobility channels is shown in Table 5.

The downlink cell capacity for voice service under different mobility channel conditions can be estimated using Equation 12. The interference factor is assumed to be 0.3 (-5dB). The voice activity factor is 0.6 and the overhead channel power percentage is 25%. Depending on the channel, the orthogonality factor varies from 0.1 (AWGN) to 0.7 (case 2). The result is shown in Table 5.

Table 5 Downlink Cell Capacity for Voice Service  
(in terms of number of simultaneous voice calls)

	AWGN	Case 1	Case 2	Case 3	Target BLER
Target E <sub>b</sub> /N <sub>t</sub>	5.1 dB	13.4 dB	10.8 dB	7.8 dB	1 %
Pole Capacity	299	30	32	94	
80% Loading Capacity	239	24	26	76	

Again, the capacity estimations given in Table 5 could be conservative since they are based on the minimum requirements specified of Release-99. The actual target E<sub>b</sub>/N<sub>t</sub> values could be lower, hence could result in higher capacity numbers (especially for the Case 1 and Case 2 mobility channels). On the other hand, the pole capacity assumes the infinite cell transmission power. From this perspective, the estimation could be optimistic since in practice systems the cell transmission power is finite.

It is also worth while to point out here that the pole capacity estimation does not take into account the channelization code limit into account. The downlink capacity for a practical system could be lower due the shortage of available channelization codes. More discussion on the channelization code is given in Section 4.3.

The UMTS Release-99 minimum performance requirements also specify the maximum ratio E<sub>c,DPCH</sub>/I<sub>or</sub> for each mobility channel. Therefore, the downlink capacity number can also be computed using Equation 11. Table 6 below shows the estimated capacity numbers based on the maximum E<sub>c,DPCH</sub>/I<sub>or</sub>. Here, the same voice activity factor (0.6) and the same geometry (5 dB) are assumed. Instead of the maximum E<sub>c,DPCH</sub>/I<sub>or</sub>, the adjusted E<sub>c,DPCH</sub>/I<sub>or</sub> is used to estimate the capacity. The adjustment is needed since the minimum performance tests in Release-99 are not

performed with the geometry of 5 dB. To obtain the adjusted  $E_{c,DPCH}/I_{or}$  with respect to the average geometry, Equation 5 is used.

$$\left(\frac{E_b}{N_t}\right)_{target} = \frac{W}{R_b} * \frac{E_{c,DPCH}}{I_{or}} * \frac{\hat{I}_{or}}{I_{oc}} \quad \text{[Equation 13]}$$

Here, to maintain the desired target  $E_b/N_t$ , which is determined by the target BLER, the  $E_{c,DPCH}/I_{or}$  is kept to be inversely proportional to the geometry  $\hat{I}_{or}/I_{oc}$ . If the geometry is increased by X dB (which means the interference is decreased by X dB), the  $E_{c,DPCH}/I_{or}$  needs to be decreased by X dB.<sup>4</sup>

Table 6 Downlink Cell Capacity for Voice Service Based on  $E_{c,DPCH}/I_{or}$   
(in terms of number of simultaneous voice calls)

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-16.6 dB	-15.0 dB	-7.7 dB	-11.8 dB	1 %
Adjusted $E_{c,DPCH}/I_{or}$	-22.6 dB	-11.0 dB	-15.7 dB	-19.8 dB	1%
Capacity	227	16	46	119	

Note the capacity numbers in Table 6 is different from the numbers given Table 5. This is due to the fact that the minimum performance requirements are not specified at the geometry of 5 dB. Although the adjustment is made in the table, it is only an approximation. As a result, the capacity numbers are also approximations.

Nevertheless, the relative trend is still valid. That is, as in the uplink, the cell capacity is very sensitive to the mobility channels. For instance, the capacity number is significantly lower for the mobility Case 1 and Case 2, compared with the mobility channel Case 3.

### 2.2.2 Circuit Switched Data Capacity

The cell capacity for CS data is given in Table 7. The numbers are computed based on minimum performance requirement (i.e., the maximum  $E_{c,DPCH}/I_{or}$ ) specified in Release-99. The data rate is 64 kbps and the activity factor is 1.0. The target BLER is set at 1%.

Table 7 Downlink Cell Capacity for Video Telephony Based on  $E_{c,DPCH}/I_{or}$   
(in terms of number of simultaneous CS calls)

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-12.8 dB	-10.0 dB	-2.7 dB	-7.4 dB	1 %
Adjusted $E_{c,DPCH}/I_{or}$	-18.8 dB	-6.0 dB	-10.7 dB	-15.4 dB	1 %
Capacity	57	3	9	26	

<sup>4</sup> The inversely proportional relationship between  $E_{c,DPCH}/I_{or}$  and the geometry is only an approximation. It didn't take into account the orthogonality factor variation as the geometry changes. For the purpose of capacity estimation, however, this approximation is acceptable.

### 2.2.3 Packet Switched Data Capacity

The cell capacity numbers for PS data for data rates 64 kbps, 144 kbps, and 384 kbps are given in Table 8, Table 9 and Table 10, respectively. The numbers are computed based on minimum performance requirement specified in Release-99. The activity factor is 1.0 and the target BLER is 10%.

Table 8 Downlink Cell Capacity/Throughput for PS Data 64 kbps Based on  $E_{c,DPCH}/I_{or}$

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-13.1 dB	-13.9 dB	-6.4 dB	-8.1 dB	10 %
Adjusted $E_{c,DPCH}/I_{or}$	-19.1 dB	-9.9 dB	-14.4 dB	-16.1 dB	10 %
Capacity	61	7	21	31	
Max Throughput	3.9 Mbps	0.5 Mbps	1.3 Mbps	2.0 Mbps	

Table 9 Downlink Cell Capacity/Throughput for PS Data 144 kbps Based on  $E_{c,DPCH}/I_{or}$

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-9.9 dB	-10.6 dB	-8.1 dB	-9.0 dB	10 %
Adjusted $E_{c,DPCH}/I_{or}$	-15.9 dB	-6.6 dB	-10.1 dB	-11.0 dB	10 %
Capacity	29	3	8	9	
Max Throughput	4.2 Mbps	0.5 Mbps	1.1 Mbps	1.4 Mbps	

Table 10 Downlink Cell Capacity/Throughput for PS Data 384 kbps Based on  $E_{c,DPCH}/I_{or}$

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-5.6 dB	-6.3 dB	-5.5 dB	-5.9 dB	10 %
Adjusted $E_{c,DPCH}/I_{or}$	-11.6 dB	-2.3 dB	-4.5 dB	-4.9 dB	10 %
Capacity	10	1	2	2	
Max Throughput	4.2 Mbps	0.5 Mbps	0.8 Mbps	0.9 Mbps	

It can be seen in Table 8, Table 9 and Table 10 that the maximum cell throughputs decrease as the DPCH data rates increase for the mobility channels Case 2, and Case 3. It seems that assigning lower data rate to each data call is more efficient, in terms of achieving high cell throughput, than assigning high data rate. The cause of this behavior is the downlink transmission power limiting. The power limiting occurs when the node-B cannot provide desired transmission power during deep fades, which results in reduced power control efficiency, hence the reduced cell throughput. To improve the cell throughput, the cell coverage for high data rate calls needs to be reduced. More coverage related discussion will be given in Section 4.

A more detailed explanation of this behavior is the fact that Release-99 minimum performance requirements are specified at different geometry for the mobility Case 2 and Case 3. To combat the fast fading, the WCDMA fast power control lets the node-B to transmit more power during

deep fades and less power otherwise. This behavior results an average transmission power increase on the DPCH, referred to as *power control margin*. The power control margin is different when there is a limit on the transmission power and depends on the transmission power headroom. The geometry is set to -3dB, 3 dB and 6 dB for the test of PS 64 kbps, PS 144 kbps and PS 384 kbps, respectively. At different geometry, the transmission headroom is different, hence the power control margin. If we take into account the power headroom difference and make proper adjustments<sup>5</sup> to the  $E_{c,DPCH}/I_{or}$  to make them comparable, we have the following tables. Here, we see the cell throughputs become comparable.

Table 11 Downlink Cell Capacity/Throughput for PS Data 144 kbps Based on  $E_{c,DPCH}/I_{or}$

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-9.9 dB	-10.6 dB	-8.1 dB	-9.0 dB	10 %
Adjusted $E_{c,DPCH}/I_{or}$	-15.9 dB	-6.6 dB	-10.6 dB	-12.5 dB	10 %
Capacity	29	3	9	13	
Max Throughput	4.2 Mbps	0.5 Mbps	1.2 Mbps	1.9 Mbps	

Table 12 Downlink Cell Capacity/Throughput for PS Data 384 kbps Based on  $E_{c,DPCH}/I_{or}$

	AWGN	Case 1	Case 2	Case 3	Target BLER
Maximum $E_{c,DPCH}/I_{or}$	-5.6 dB	-6.3 dB	-5.5 dB	-5.9 dB	10 %
Adjusted $E_{c,DPCH}/I_{or}$	-11.6 dB	-2.3 dB	-6.5 dB	-8.4 dB	10 %
Capacity	10	1	3	5	
Max Throughput	4.2 Mbps	0.5 Mbps	1.3 Mbps	2.0 Mbps	

## 2.3 Mixed Traffic Capacity

When multiple services are considered, such as when voice, CS data and PS data services are all provided by the network, the WCDMA cell capacity will no longer be a single number. Instead, it is represented by a region, referred to as the *capacity region*. Each point in the capacity region corresponds to a certain traffic mix.

To determine the capacity region, we can again start from the pole capacity. For the uplink, Equation 14 can be extended to the mixed traffic scenario. Let  $N_i$  be the number of users of the  $k^{th}$  type of traffic with the data rate  $R_{b,k}$ , the signal-to noise ratio target  $(E_b/N_t)_k$  and the activity factor  $v_k$ . Let the vector  $(N_0, N_1, \dots, N_K)$  denote the traffic mix of k different service-mobility-channel combinations. The vector  $(N_0, N_1, \dots, N_K)$  is a point in the mixed traffic capacity region if it satisfies this condition.

<sup>5</sup> In practical system, the power control margin can be proper controlled to be more consistent by properly setting the power limiting range of each DPCH.

$$\sum_k^K N_k * \left(\frac{E_b}{N_t}\right)_k * \left(\frac{R_{b,k}}{W}\right) * v_k * (1 + \alpha) \leq 1 \quad \text{[Equation 15]}$$

Consider the mixed traffic with two types of services, 12.2 kbps voice and 64 kbps PS data. Assume the mobility channel for the voice is Case 3 and the channel for the 64 kbps PS data is AWGN. Based on the minimum performance requirement in Release-99, the maximum  $E_b/N_t$  targets for the two types of traffic are 7.2dB and 1.5 dB, respectively. Given the activity factors 0.6 and 1.0 for voice and PS data, respectively, the capacity region for this traffic mix is plotted in Figure 1.

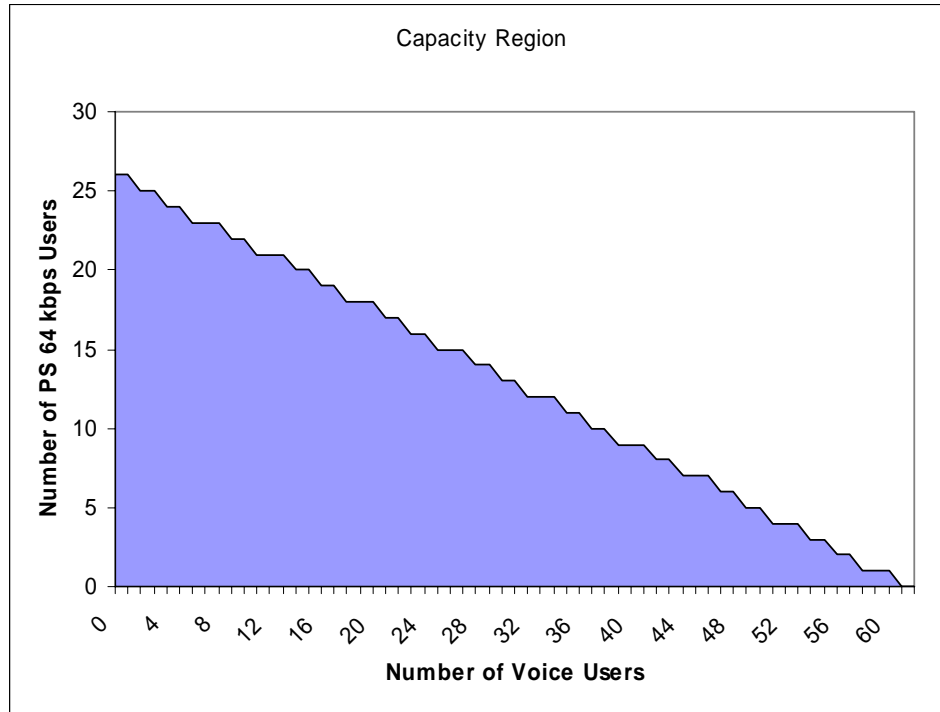


Figure 1 Uplink Capacity Region of Voice and PS Data Mixed Traffic

For the downlink, a similar condition can also be obtained by extending Equation 16 to the mixed traffic environment, as shown in Equation 17.

$$\sum_k^K N_k * \left(\frac{E_b}{N_t}\right)_k * \left(\frac{R_{b,k}}{W}\right) * v_k * (\delta + \beta) \leq 1 - \eta_{OH} \quad \text{[Equation 18]}$$

As an example, Figure 2 shows the contours of capacity regions with 3 different services: voice, CS 64 kbps data, and PS data. Each contour line represents the capacity region boundary of a voice and CS 64 kbps data mixed service with respect to a given PS data throughput. The assumptions for computing these capacity regions are given in Table 13. In addition to Table 13, we also assume the overhead channel power is 25% of the total cell transmission power ( $\eta_{OH} = 0.25$ ), and the orthogonality factor ( $\delta$ ) and interference factor ( $\beta$ ) are 0.4 and 0.31 (-5dB), respectively.

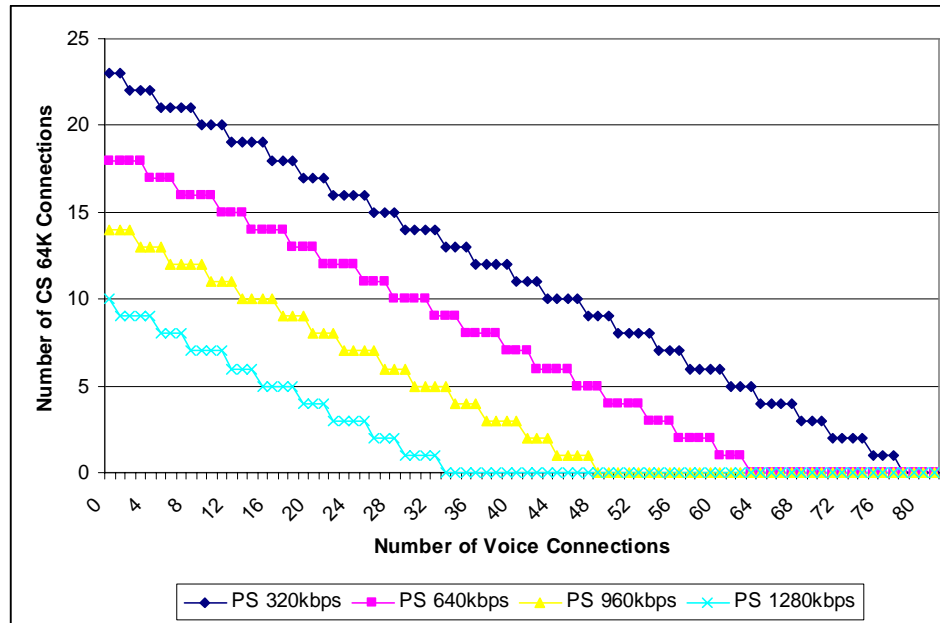


Figure 2 Downlink Capacity Region with Voice, CS and PS Data Services

Table 13 Assumptions of Computing Downlink Capacity Region

	Voice Service	CS 64K Data Service	PS Data Service
Mobility Channel	Case 3	Case 3	Case 3
Target $E_b/N_t$	7.6 dB	3.6 dB	3.0 dB
Activity Factor $\nu$	0.6	1.0	1.0
Data Rate $R_b$	12.2kbps	64 kbps	

### 3 Release 5 HSDPA Capacity

HSDPA uses a constant transmission power with fast link adaptation where the effective coding rate and modulation are adjusted to account for changes in the radio condition. This is fundamentally different from the fast power control with fixed coding and modulation employed in Release 99, where the transmission power is adjusted so that a target Signal-to-Interference Ratio (SIR) is achieved. With HSDPA, the peak data rate of individual user equipment (UE) is a function of the UE location (i.e. the distance from the antenna) and the propagation conditions associated with the UE. The amount and technique used to allocate power to HSDPA plays a key role in the resulting cell throughput distribution. Therefore, it is very hard to evaluate the

HSDPA capacity analytically. Instead, field tests and numerical simulations are often used to determining the HSDPA cell throughput.

For Release-5, the downlink transmission is improved by the introduction of HSDPA. No major improvement is made in the uplink. The uplink capacity for voice and data applications, therefore, is the same as the capacity for Release-99.

### 3.1 HSDPA Cell Throughput

Table 15 presents the simulation result of HSDPA cell throughput. The simulations assume a suburban environment, with users distributed according to three scenarios as shown in Table 14. Each scenario assumes a different mix of users with Pedestrian A 3 kmph (PA3), Pedestrian B 3 kmph (PB3), and Vehicular A 30 kmph (VA30) mobility channel conditions: In Scenarios 1 and 2, all users are distributed in an environment with significant multipaths. In Scenario 3, 25% of all users are in a PA3, i.e., with a strong dominant path, representing in-building or microcell circumstances, among others.

Table 14 HSDPA performance simulation scenarios

Channel Model	Scenario 1	Scenario 2	Scenario 3
PA3	0%	0%	25%
PB3	75%	50%	50%
VA30	25%	50%	25%

A full traffic buffer is assumed in the simulation such that all users always have data to send. Table 15 shows the cell throughput results for each scenario under two conditions: first, 16-QAM modulation becomes available; second, the number of supported HS-PDSCH codes increases from 5 to 15. A Proportional Fair Scheduler is assumed for the simulation.

Table 15 Simulated HSDPA Cell Throughputs

Scenario	Number of Codes/ HS-PDSCH	Availability of 16-QAM	Cell Throughput [Mbps]
1	5	No	1.780
	5	Yes	1.783
	15	No	2.017
	15	Yes	2.023
2	5	No	1.519
	5	Yes	1.523
	15	No	1.750
	15	Yes	1.754

Scenario	Number of Codes/ HS-PDSCH	Availability of 16-QAM	Cell Throughput [Mbps]
3	5	No	2.171
	5	Yes	2.301
	15	No	2.404
	15	Yes	2.573

In Table 15, first consider the number of HS-PDSCH codes. When 15-code UEs are employed instead of 5-code UEs, cell throughput increases by approximately 12% to 15%. Next, consider the introduction of 16-QAM modulation. This increases throughput only negligibly compared to the QPSK-only UEs for Scenarios 1 and 2. Only for Scenario 3 is the impact of 16-QAM noticeable, increasing throughput approximately 6% to 9% compared to the QPSK-only UEs. Overall, the maximum obtainable cell throughput--obtained by increasing the number of codes the UEs can support from 5 to 15 and introducing 16-QAM modulation--is nominally 18%.

The following tables (Table 16 and Table 17) present the field measurement of the HSDPA cell throughput as a function of number of UEs in the cell. (All the UEs are set at the same location during the test.) Round Robin and Proportional Fair scheduling algorithms were tested. The cell could support maximum of 5 code channels.

Table 16 shows the cell throughput with a Round Robin scheduler. The throughput is about 1.26 Mbps to 1.45 Mbps.

Table 16 : Cell Throughput with Round Robin Scheduling

FTP Throughput [kbps]	1x UE	2 x UE	3 x UE	4 x UE	5 x UE	6 x UE
UE 1	1263.8	714.4	437.5	345.9	284.7	239.1
UE 2		757.2	508.4	369.6	302.5	247.3
UE 3			456.6	369.8	271.7	242.6
UE 4				367.8	298.5	236.5
UE 5					168.1	179.5
UE 6						213.9
Cell	1263.8	1471.6	1402.5	1453.1	1325.6	1359.0

Table 17 shows the cell throughput with a Proportional Fair scheduler. The throughput is about 1.32 Mbps to 1.44 Mbps.

Table 17 : Cell Throughput with Proportional Fair Scheduling

FTP Throughput [kbps]	1 x UE	2 x UE	3 x UE	4 x UE	5 x UE	6 x UE
UE 1	1320.7	705.9	476.3	362.9	288.1	256.4
UE 2		721.1	446.4	369.3	287.8	243.0
UE 3			468.2	359.9	286.2	240.3
UE 4				329.8	253.4	227.8
UE 5					281.2	238.2
UE 6						236.1
Cell	1320.7	1426.9	1390.9	1421.9	1396.7	1441.7

In those tests, no significant difference is observed between the two types of schedulers. This is largely due to all the UE being in similar RF conditions. When the UE are in significant different radio conditions, say uniformly distributed over the cell, simulations have shown that the gain due to the proportional fair scheduler over the round robin scheduler can reach 1.75.

### 3.2 Average Cell Throughput

When HSDPA is deployed to share the same carrier with the Release-99 system, HSDPA cell throughput can vary with allocated power.



Figure 3 HSDPA Power vs Cell Throughput

In Figure 3, the simulation shows the throughput as a function of allocated power for two different category UEs. Category 8 UEs support 10 codes with peak data rate up to 7.2 Mbps and Category 12 UEs support 5 codes with maximum data rate support of 1.8 Mbps. It can be seen that maximum HSDPA cell throughput is a linear function of the allocated HSDPA power.

### 3.3 Average Cell Throughput vs. Voice Load

An urban channel model with a 75% and 25% mix of Vehicular A and Pedestrian A users in a 12.2 kbps RB of Release-99 at cell edge link budget was used for simulating the voice traffic.

Figure 4 shows the HSDPA average cell throughput decreases as the number of voice users in the cell increases. The curve is slightly concave indicating there is an optimum balance between the HSDPA throughput and the voice load.

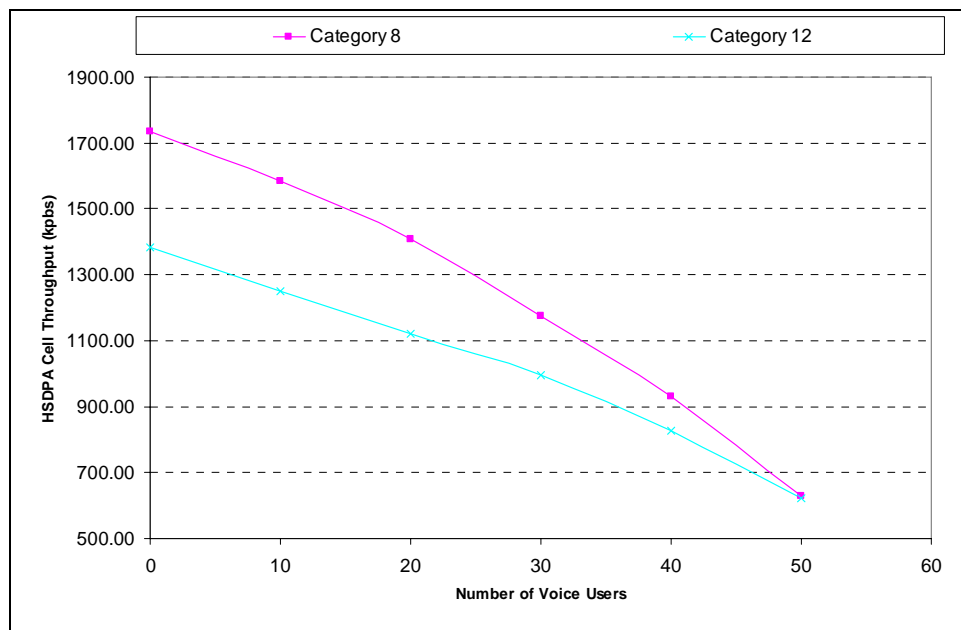


Figure 4 HSDPA Average Cell Throughput vs Voice Load

## 4 Other Capacity Issues

In the earlier sections, we have illustrated how to estimate the WCDMA cell capacity using the pole capacity as a function of the mobility channel type and traffic type, or the traffic mix. It is important to point out, however, that the capacity estimates based on the pole capacity formula will not give the whole picture of a WCDMA network capacity. There are other parameters affecting the WCDMA cell capacity, such as the desired coverage, the orthogonal variable

spreading factor (OVSF) code limitation, the soft handover impact, the capacity consumption of signaling, etc. When using the capacity estimates to determine the network capacities, we need to make sure proper considerations are given to these parameters.

## 4.1 Coverage

In the pole capacity formula, the cell coverage is not considered since it assumes sufficient (up to infinite) transmission power. In practice, both downlink and uplink transmission power is limited. Hence, the cell coverage should be studied whenever the cell capacity is evaluated. For instance, the downlink voice capacities for mobility channel Case 1 and Case 2 are 16 and 46, respectively, as shown in Table 6. The numbers 16 and 46 are obtained assuming the average geometry in the cell at 5 dB. This geometry value corresponds to a large coverage scenario when significant portion of mobility Case 2 and Case 3 users are distributed away from the cell site. If the coverage for the mobility channel Case 1 and 2 is reduced, i.e. only the Case 1 and Case 2 users that are distributed close to the cell site can be served, the corresponding average geometry will increase. Assuming the average geometry is increased from 5 dB to 7 dB due to the coverage reduction, the corresponding pole capacities are doubled as shown in Table 18.

Table 18 Downlink Cell Capacity for Voice Service with Reduced Coverage

	Case 1	Case 2
Maximum $E_{c,DPCH}/I_{or}$	-15.0 dB	-7.7 dB
Adjusted $E_{c,DPCH}/I_{or}$	-13.0 dB	-17.7 dB
Capacity	25	73

Table 18 shows for a 2 dB increase of average geometry the capacity increase is also about 2 dB. From a practical point of view, the reduction of the average cell geometry can be achieved by placing the serving nodes in high tele-traffic area.

## 4.2 Soft Handover and Cell Capacity

The impact of soft handover in estimating cell capacity is two fold. On the one hand, the soft handover allows the UE to communicate with multiple cells. To achieve the same BLER, the required transmission power decreases during the soft handover. This power reduction is true for both uplink and each radio link on the downlink, resulting in the cell capacity increase in both uplink and downlink. For instance, consider the downlink capacity in Equation 11. The transmission power reduction on downlink means lower  $E_{c,DPCH}/I_{or}$ . Therefore, the downlink capacity becomes higher.

On the other hand, a call in soft handover will consume the capacity of all the cells in the active set. Therefore, the capacity of the WCDMA network is not simply the sum of the capacity of each WCDMA cell. Duplications due to soft handover should be taken into account when computing the network capacity to avoid double counting.

### 4.3 OVSF Code Limitation

In Release-99, each downlink DPCH is associated with a unique OVSF code and the total number of available OVSF codes in a WCDMA cell is fixed (i.e. finite). (For simplicity, we don't consider the scenario of using the secondary scrambling code here since most commercial WCDMA networks do not have the secondary scramble code support.) Hence, the downlink cell capacity is assumed to be bounded by the total amount of OVSF codes available.

In the pole capacity analysis, the OVSF code limitation is not considered. That is, we assume there are always unique OVSF codes available for all the calls in the cell. In reality this is not true. Therefore, to accurately evaluate the network capacity, we should always check the cell capacity estimation against the OVSF code limitation. For instance, the total number of available OVSF code for the 12.2 kbps voice service is less than 128 (typically 125 OVSF codes would be available, once the codes necessary to support the common control channels are discounted). Although the downlink pole capacity on the AWGN channel is 299 as shown in Table 5, this pole capacity will never be reached when the OVSF code limitation is considered.

The total number of available OVSF codes is a function of the soft handover performance. During soft handover, a single call consumes multiple OVSF codes, one from each cell in the active set. This behavior effectively reduces the total number of available OVSF codes in each cell. The effective available OVSF codes in each cell decreases as the percentage of calls in soft handover increases.

## 5 Conclusion

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The paper presents a way of using simple pole capacity formulae to obtain the WCDMA cell capacity estimation with respect to different mobility channel and service type scenarios, by assuming proper  $E_b/N_t$  target values or traffic-to-total power ratio  $E_{c,DPCH}/I_{or}$ . This approach provides quick means to obtain approximate capacity estimates for the operators to make business and technical decisions at the early stages of the network planning.

When applying the estimates, however, one should also pay attention to other factors that can affect the cell or network capacity, which include, but not limited to, targeted coverage, OVSF code limitation, soft handover performance, and other hardware limitations, etc. Also while these factors are being considered during the formal network planning, a good understanding of their impacts is crucial to the successful adoption of the capacity estimation for eventual deployment.

## References and Further Readings

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