# UPLINK CAPACITY OF ALL-PACKET-SERVICE WCDMA MOBILE INTERNET SYSTEMS IN EMI ENVIRONMENT

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**Abstract:** In this paper, the impacts of noise rise and external Electromagnetic Interference (EMI) to the uplink capacity and coverage of all-packet-service WCDMA mobile Internet systems is presented. Specifically, the capacity in term of total throughput per cell in different environments is presented in this study. Comparisons in term of pole capacity in the external EMI environment are made regarding the data rates of 144 kbps and 384 kbps packet traffic. As expected, the results in this paper indicate that when the system utilizes higher load factor, the cell coverage would be reduced. The analysis in this study is based on certain assumptions, chosen as realistic as possible. The results described in this paper will be a valuable contribution towards 3G mobile Internet system designs.

**Keywords:** WCDMA, Noise rise, external EMI, Uplink capacity, Coverage, and Packet traffic.

## 1. Introduction

Reduction of the capacity in CDMA cellular systems due to increasing background noise and interference assuming the Okumura-Hata propagation model has been derived in the existing literature [1]-[3]. However, addressed here is a study on the impact of noise rise and external EMI to the uplink capacity of all-packet-service WCDMA systems. The methods described in this paper can be used for rough estimates suitable in the dimensioning process.

## 2. Load Equation and Noise Rise

The theoretical spectral efficiency of a WCDMA cell can be calculated from the load equation. The uplink load factor can be written as [4]:

$$\eta_{UL} = \frac{E_b/N_o}{W/R}.N.v.(1+i) \qquad (1)$$

where
$N$ is the number of users per cell.
$v$ is the activity factor of user at the physical layer (0.67 for speech and 1.0 for data).
$W$ is the WCDMA chip rate (3.84 Mcps).
$R$ is the bit rate of user.
$i$ is other cell to own cell interference ratio seen by the base station receiver.

The noise rise is defined as the ratio of the total received wideband power ($I_{total}$) to the noise power ($P_N$) as:

$$Noise\,rise = \frac{I_{total}}{P_N} = \frac{1}{1-\eta_{UL}} \qquad (2)$$

The load equation predicts the amount of noise rise over thermal noise due to interference. The required $E_b/N_o$ can be derived from link level simulations and from measurements. The other cell to own cell interference ratio $i$ is a function of cell environment or cell isolation and antenna pattern.

Generally, the load equation is used to make a semi-analytical prediction of the average capacity of a WCDMA cell, without going into system-level capacity simulations. Specifically, this load equation can be utilized for predicting cell capacity and planning noise rise in dimensioning process.

When $\eta_{UL}$ in Eq. (1) becomes close to 1, the corresponding noise rise approaches to infinity and the system has reached its pole capacity ($M_{max}$). Therefore, the Eq. (1) can be modified and the pole capacity equation can be written as:

$$M_{\max} = \left(1 + \frac{W}{R(E_b/N_o)v}\right)\frac{1}{(1+i)} \qquad (3)$$

where
$i$ depends on the characteristics of the cell plan such as numbers of sectors, wave propagation characteristics, log-normal fading and antenna beam width. The following values are used to calculate the pole capacity in different cell configurations in this paper [5]:

| | |
|---|---|
| Omni-directional: | $i = 0.67$ |
| Three-sector: | $i = 0.93$ |
| Micro cell: | $i = 0.4$ |

## 3. The Impact of Noise Rise to the Data Throughput

This section presents the impact of noise rise to the capacity in term of the total throughput per cell in different cell configurations. The uplink noise rise in different cell configurations is shown in Fig.1 for data service, assuming an $E_b/N_o$ requirement of 1.5 dB [4]. Referring to Eq. (2), the noise rise of 3.0dB corresponds to a 50% load factor, and the noise rise of 6.0dB to a 75% load factor. Indicated in Fig. 1, a throughput of 700kbps in the three-sector cell can be supported with 3dB noise rise (50% load factor), and 1050kbps with 6.0dB noise rise (75% load factor). Table 1 shows the throughput of three types of cell configurations with 50% and 75% load factors.

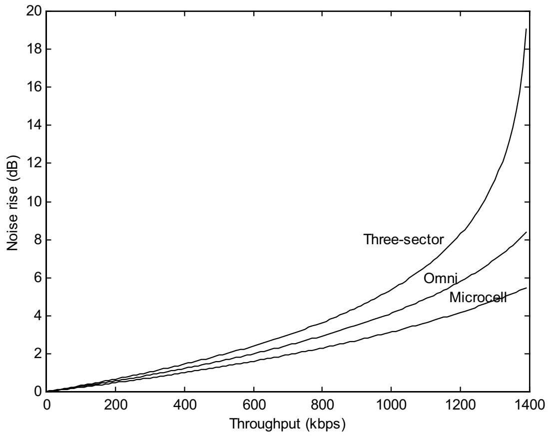


**Fig. 1** Uplink noise rise as a function of uplink data throughput in different cell configurations: three-sector, omni-directional, and micro-cell.

**Table 1** Throughput of three types of cell configuration with 50% and 75% load factors.

| Cell configuration | 3.0dB noise rise (50% load) | 6.0dB noise rise (75% load) |
|---|---|---|
| Omni-directional | 800 kbps | 1200 kbps |
| Three-sector | 700 kbps | 1050 kbps |
| Microcell | 900 kbps | 1450 kbps |

## 4. The Impact of External EMI to the Pole Capacity

In this section, the effect of the external EMI to the pole capacity is studied. The external EMI needs to be considered, because it will affect all wideband systems where the systems are located in high-noise environment. The uplink pole capacity, $M_{max}$, is the theoretical limit for the number of UEs that a cell can support.

Basically, the WCDMA radio network has been planned for 75% load [3]. In case the system does not have accurate information about the external interference level there can be significant capacity loss. Practically, for the worst-case scenario, we assume that 15% of the loading is caused by EMI [3].

**Table 2** Uplink and $E_b/N_o$ (Vehicular speed at 120km/hr)

| Service | $E_b/N_o$ |
|---|---|
| Packet 64 kbps | 3.9 |
| Packet 128 kbps | 3.4 |
| Packet 384 kbps | 3.4 |

When using Table 2, the conditions are the following:

- The bitrate offered by the various services is the peak rate and indicates the maximum throughput at 100% utilization.
- The $E_b/N_o$ figures were obtained at the packet switched data: BLER 10%

After calculating the $M_{max}$, Table 3 shows the $M_{max}$ values of the uplink. Now, the uplink capacity of a three-sector site at maximum loading can be calculated.

**Table 3** Typical uplink $M_{max}$ values at 100% load for a three-sector site configuration with fast fading at 120km/hr.

| Service | $M_{max}$ Three-sector |
|---|---|
| Packet 64 kbps | 13.67 |
| Packet 144 kbps | 8.11 |
| Packet 384 kbps | 3.36 |

This example shows how to calculate the number of simultaneous users per cell for high-mobility (120km/hr) case and at data rate 64 kbps:

1) For the packet 64 kbps in urban and high-mobility (120km/hr) environment a three-sector site, in Table 3, $M_{max}$ is about 13.
2) At 75% loading this is equivalent to $M_{max}$ = 9.75, or a site capacity of 3×9 = 27

Following the procedure above, the pole capacity ($M_{max}$) at 75% load for the uplink in each case can be shown in Table 4.

**Table 4** $M_{max}$ of uplink at 75% load for a three-sector site configuration with fast fading at 120km/hr.

| Service | $M_{max}$ Three-sector |
|---|---|
| Packet 64kbps | 27 |
| Packet 144kbps | 18 |
| Packet 384kbps | 4 |

As addressed in section 3, for the worst-case scenario, we found that 15% of the loading is caused by EMI [3]. Therefore, the loading in case of external interference is 75% − 15% = 60%. There will be 60/75 = 80% less users in the network.

The results in Table 5 demonstrate the impact of the external EMI to the pole capacity. It is shown that the reduction of the pole capacity is caused by the external EMI.

**Table 5** Comparison of $M_{max}$ between with and without the external EMI

| Service | $M_{max}$ Three-sector Without EMI | $M_{max}$ Three-sector With EMI |
|---|---|---|
| Packet 64kbps | 27 | 21 |
| Packet 144kbps | 18 | 14 |
| Packet 384kbps | 4 | 3 |

## 5. The Impact of Noise Rise to the Cell Coverage

This section outlines how to calculate cell coverage of the WCDMA cellular network. The objective of this section is to study the impact of noise rise to the cell coverage.

First of all, it is important to know where are the reference points of the RBS because the RF characteristic requirements and measurements will be referred to these points. There are two sets of reference points for the Receiver (RX) and the Transmitter (TX) depending whether Tower Mounted Amplifier (TMA) is used or not, see Fig. 2 [5]:

– Scenario A, in where RX and TX reference point are set at the AIU input and output ports respectively.

– Scenario B, in where the RX and TX reference points are set at the TMA's antenna port.

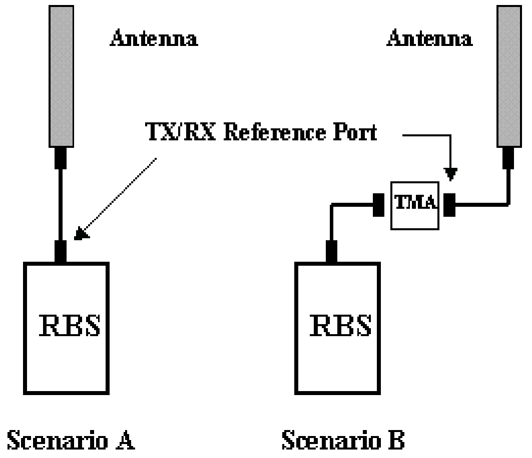


**Fig. 2** RBS reference points

### 5.1 Link budget analysis

The link budget of the WCDMA uplink is presented in this subsection. The schematic of the link budget in Fig. 3 is used to equate a link budget equation [3].

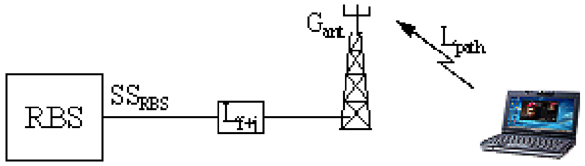


**Fig. 3** Schematic of components included in the link budget. Abbreviations have the following meaning; G=Gain, L=Loss, ant=antenna, f+j=feeder and jumper.

To analyze the link budget in WCDMA systems, an expression can be equated as [3]:

$$SS_{RBS} = P_{UE} - L_{path} + G_{ant} - L_{f+j} \geq SS_{design} \quad (4)$$

where the design criterion, $SS_{design}$, is equal to the sensitivity of the radio base station, $RBS_{sens}$, plus a number of margins as:

$$SS_{design} = RBS_{sens} + BL + CPL + BPL + PC_{marg} + I_{UL} + LNF_{marg} \quad (5)$$

where:

$L_{path}$ is the path loss (on the uplink) (dB).
$P_{UE}$ is the maximum UE output power (= 21 or 24) (dBm).
$RBS_{sens}$ is the RBS sensitivity. It depends on the RAB (dBm).
$LNF_{marg}$ is the log-normal fading margin (this margin depends on the environment and the desired degree of coverage) (dB).
$I_{UL}$ is the noise rise (dB).
$PC_{marg}$ is the power control margin, dependent on channel model (dB).
$BL$ is the body loss (= 0 or 3)(dB).
$CPL$ is the car penetration loss (= 6) (dB).
$BPL$ is the building penetration loss (dB).
$G_{ant}$ is the sum of the RBS antenna gain and UE antenna gain (dBi).
$L_{f+j}$ is the loss in feeders and jumpers (dB).

The maximum pathloss allowed, $L_{pathmax}$, is obtained when $SS_{RBS} = SS_{design}$ so solving for $L_{pathmax}$ we obtain

$$L_{pathmax} = P_{UE} - RBS_{sens} - I_{UL} - LNF_{marg} - PC_{marg} - BL - CPL - BPL + G_{ant} - L_{f+j} \quad (6)$$

The sensitivity of a WCDMA RBS ($RBS_{sens}$) is dependent on the user data rate, the $E_b/I_o$ (bit energy over interference energy), the thermal noise figure and the RBS noise figure. The data rate and $E_b/I_o$ are dependent on the particular Radio Access Bearer, RAB and channel model used. The Unloaded RBS sensitivity (i.e. the sensitivity level without any interference contribution from other UEs) can be expressed as:

$$RBS_{sens} = N_t + N_f + 10\cdot\log(R_{user}) + E_b/I_o \quad (7)$$

where

$N_t$ is the thermal noise power density (–174 dBm/Hz)
$N_f$ is the noise figure (3 dB with TMA and 4 dB without TMA)
$R_{user}$ is the user bit rate (information bits per second, excluding retransmission)
$E_b/I_o$ is the bit energy level over noise level

In Table 4, some RBS sensitivity levels with TMA are given [5]:

**Table 4** RBS sensitivity levels (dBm) with TMA. The figures are given at the TMA antenna connector.

| Service | RBS sensitivity levels |
|---|---|
| Speech 12.2 kbps | –125.9 dBm |
| Circuit 64 kbps | –119.0 dBm |
| Packet 144 kbps | –118.0 dBm |
| Packet 384 kbps | –114.0 dBm |

There are four UE classes defined for WCDMA. The maximum output powers are listed in Table 5. However, present study in this paper focuses on UE class 3, which is the data terminal class [5].

**Table 5** User Equipment output power at the antenna connector.

| Class | Output power (dBm) |
|---|---|
| 1 | 33 |
| 2 | 27 |
| 3 | 24 |
| 4 | 21 |

### 5.2 Cell Coverage

When roughly estimating the size of macro cells, without respect to specific terrain features in the area, a fairly simple Okumura-Hata propagation formula is often used. However, it must be noted that the Okumura-Hata formula only can be used for rough estimates. For small cells in an urban environment the Okumura-Hata formula is not valid. Therefore, the COST 231-Walfish-Ikegami model is selected for this study because it gives a better approximation for the cell radius in urban environments. The path loss according to Walfish-Ikegami is [3]:

$$L_{path} = 155.3 + 38\log R - 18\log(H_b - 17) \quad (dB) \qquad (8)$$

$$R = 10^{\alpha}, \text{ where } \alpha = [L_{path} - 155.3 + 18\log(H_b - 17)]/38 \qquad (9)$$

A base station antenna height ($H_b$) of 30 m and a UE with antenna height ($H_m$) of 1.5 m is used in this study. Table 6 provides a reference table. For simplicity, the same data rate on each UE is assumed and provided uniformly over the cell area in this study. From section 3, the noise rise of 3.0dB corresponds to a 50% load factor, and the noise rise of 6.0dB to a 75% load factor.

**Table 6** Uplink budget for 144 kbps and 384 kbps packet traffic and 95% probability of coverage [3], [5] with 3dB and 6dB noise rise.

| Parameter | 144 kbps | 384 kbps |
|---|---|---|
| $P_{UE}$ (for data terminal) | 24.0 | 24.0 |
| $RBS_{sens}$ | -118.0 | -114.0 |
| $LNF_{marg}$ | 5.9 | 5.9 |
| $PC_{marg}$ | 2.0 | 2.0 |
| $I_{UL}$ | **3.0/6.0** | **3.0/6.0** |
| $BL$ | 0 | 0 |
| $G_{ant}$ | 17.5 | 17.5 |
| $L_{f+j}$ | 0 | 0 |
| $L_{pathmax}$ (outdoor) | **148.6/145.6** | **144.6/141.6** |
| $CPL$ | 6.0 | 6.0 |
| $L_{pathmax}$ (in-car) | **142.6/139.6** | **138.6/135.6** |
| $BPL$ | 18.0 | 18.0 |
| $LNF_{marg}$ | 9.0 | 9.0 |
| $L_{pathmax}$ (indoor) | **127.5/124.5** | **123.5/120.5** |

**Table 7** Coverage with 95% probability of coverage.

| Environment | 3.0dB noise rise 50% load | 6.0dB noise rise 75% load | Δ (%) |
|---|---|---|---|
| 144kbps Outdoor urban | 2.25km | 1.90km | 15.56% |
| 384kbps Outdoor urban | 1.75km | 1.50km | 14.29% |
| 144kbps In-car urban | 1.70km | 1.40km | 17.65% |
| 384kbps In-car urban | 1.25km | 1.05km | 16.00% |
| 144kbps Indoor urban | 0.60km | 0.50km | 16.67% |
| 384kbps Indoor urban | 0.48km | 0.40km | 16.67% |

By using parameters in Table 6 to calculate the cell coverage, the results in Table 7 indicate that when the system utilizes higher load factor, the cell coverage would be reduced. Moreover, it can also be observed that the impacts of the noise rise to the reduction of the cell coverage in Table 7 is approximately about 14% - 17%. The results presented in Table 7 confirm that the microcell system is suitable for the high-speed mobile Internet network [3].

For the further study, an interesting research that can be pursued comprehensively could be on the impacts of spurious emission to the cell coverage due to coexistence interference. Co-existence of mobile radio systems may cause interference resulting in performance degradation and cell coverage reduction [6].

## 6. Conclusions

Indicated in this paper, the effect of noise rise and external EMI can be seen as a reduced uplink capacity which is described in details in this report. This paper also presents the impact of noise rise to the capacity in term of the total throughput per cell in different cell configurations. The impact of the external EMI to the pole capacity is also studied. It is shown that the reduction of the pole capacity is caused by the external EMI. Moreover, it can be observed that the impacts of the noise rise to the reduction of the cell coverage are approximately about 14% - 17% in all-packet-service WCDMA cellular systems. The present study contributes to the practical procedure of capacity and coverage analysis in WCDMA uplink designs. The methods described in this paper offer a practical analysis for mobile cellular engineers.

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