WCDMA Mobile Internet in High-Mobility Environment Case Study on Military Operations of the Royal Thai Armed Forces

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Abstract

The Royal Thai Armed Forces are searching for alternatives to extend users' voice, data, and video communications for high-mobility units. This paper evaluates the capacity of commercial WCDMA mobile Internet in high-mobility environment to support that a legacy military communication system in the Royal Thai Armed Forces can be replaced by the commercial WCDMA system with new capabilities and enhanced mobility, access, capacity, and quality of service.

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-FDD uplink and downlink for mobile Internet networks in the high-mobility environment. 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.

Keywords: Capacity, Uplink, Downlink, WCDMA-FDD, and High-Mobility

1. Introduction

The nature of high mobility of military operations requires wide use with high speed capacities of voice, data and image communications. Control, surveillance, reconnaissance and reporting systems play a vital role in the command and control system. Many of these requirements can be only met with the use of radio systems. The equipment of military communications adds and multiplies the power of forces. That is why, in this study, the use of WCDMA mobile Internet is evaluated as one of alternatives for successful military operations.

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.

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 indoor and local areas. It should be noticed that WCDMA TDD is mainly used for indoor coverage. This paper only deals with the pure WCDMA-based FDD mode (UTRA/FDD).

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 [2]. 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.

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 that is done for the uplink. 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 [2]. Therefore, the solution is to rely on simulations to estimate what capacity the system would be able to support at a given range.

The scope of this paper is to outline how to calculate the capacity of the WCDMA FDD radio access network. 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. In this paper, the uplink and downlink capacities of WCDMA FDD is considered in the high-mobility environment. Specifically, the maximum number of simultaneous users of uplink and downlink is calculated at mobile-terminal speed 120km/hr.

2. WCDMA FDD Specifications

The WCDMA FDD system is required to operate in the following specification as shown in Table 1. The nominal carrier spacing is 5 MHz and the chip rate is 3.84 Mcps. The carrier can be adjusted in steps of 200 kHz [3].

Table 1. Specification of WCDMA FDD system.

Uplink	1920 – 1980 MHz
Downlink	2110 – 2170 MHz
Carrier spacing	5 MHz (nominal)
Duplex distance	190 MHz
Frequency raster	200 kHz
Chip rate	3.84 Mcps

E_b/I_o characteristics are based on the simulated results in the ITU proposal [4]. Table 2 shows the recommended E_b/I_o values for the uplink and downlink respectively.

Table 2. Uplink and downlink E_b/I_o (Vehicular speed at 120km/hr)

Service	Uplink	Downlink
Speech 12.2 kbps	6.5	8.1
Packet 64 kbps	3.9	6.8
Packet 128 kbps	3.4	6.0
Packet 384 kbps	3.4	6.0

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 Eb/Io figures were obtained at the following quality thresholds:
  - Speech: BER < 10^{-3}
  - Circuit switched data: BER < 10^{-6}
  - Packet switched data: BLER 10%
- The Eb/Io figures in 2 include diversity gain.

3 Capacity of WCDMA FDD

In this section uplink and downlink capacity are addressed separately.

3.1 Uplink Capacity

The more loaded the system is, the more interference will be generated. This will have the effect that the sensitivity level is worse in a loaded system than in an unloaded one. The sensitivity degradation due to the interference is often referred to as Noise Rise and is denoted I_{ul} and is given by:

$$I_{ul} = 10 \times Log\left(\frac{1}{1 - Loading}\right) \quad (1)$$

where

Loading is the system load.

The maximum capacity is related to the amount of interference the system can accept on the uplink. The relationship between loading/interference and capacity assuming a single service can be written as:

$$Loading = 1 - 10^{\left(\frac{-I_{UL}}{10}\right)} = \frac{M}{M_{max}} \quad (2)$$

M_{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 (e.g. speech). For stability reasons it is recommended not to exceed 60% loading on the uplink.

For a multi-service system, the same equation can be re-written as:

$$Loading = \frac{M_1}{M_{\max,service1}} + \frac{M_2}{M_{\max,service2}} + \frac{M_3}{M_{\max,service3}} + etc... \quad (3)$$

where

M_n = the number of simultaneous users for the n^{th} service.

$M_{max,service,n}$ = the maximum number of simultaneous users for the n^{th} service at 100% loading.

System load is generally given in the range of 0-60% where 60% corresponds to a 4 dB margin. When the system load gets too high, the interference will increase rapidly and the system may become unstable. However, it will not be valid in micro-cell environments or other environments where a UE might be situated just a few meters from the radio base station (RBS) antenna. In such a situation the UE will not be able to regulate its output power low enough, thus the signal strength received at the RBS will exceed the desired level which leads to an increased noise level.

The maximum number of simultaneous users can easily be calculated for a certain service if the *Eb/Io* value and the information (user) bit rate is known [5]:

$$M_{\max} = 1 + \frac{1}{(1+F)(C/I)} \tag{4}$$

where the C/I is calculated as:

$$C/I = \frac{10^{(Eb/Io)/10}}{R_{chip}/R_{user}} \tag{5}$$

where

R_{chip} = Chip rate (cps)

R_{user} = Information bit rate for the service (bps)

F is the ratio between the interference from other cells and the interference generated in the own cell. This means that *F* 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 were obtained through simulations [5]:

Omni: 0.67
Three-sector: 0.93
Micro cells: 0.4

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
Speech 12.2 kbps	56.30
Packet 64 kbps	13.67
Packet 128 kbps	8.11
Packet 384 kbps	3.36

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. This example shows how to calculate the number of simultaneous users per cell for high-mobility (120km/hr) case (worst-case scenario) and at data rate 32 kbps:

1) For the packet 32 kbps in urban and high-mobility (120km/hr) environment a three-sector site, in Table 3, M_{max} is 21 (21 simultaneous users).
2) At 50% loading this is equivalent to 10 simultaneous users, or a site capacity of 3x10 = 30 simultaneous users.

Following the procedure above, the number of simultaneous users at 50% load for the uplink in each case can be shown in Table 4.

Table 4 The number of simultaneous users of uplink at 50% load for a three-sector site configuration with fast fading at 120km/hr.

Service	Simultaneous users Three-sector
Packet 32kbps	30
Packet 64kbps	18
Packet 128kbps	12
Packet 384kbps	3

3.2 Downlink Capacity

The M_{max} of downlink capacity can be calculated by following the same procedure as uplink in section 3.1. Table 5 shows the M_{max} values of the downlink. Now, the downlink capacity of a three-sector site at maximum loading can be calculated.

Table 5 Typical downlink M_{max} values at 100% load for a three-sector site configuration with fast fading at 120km/hr.

Service	M_{max} Three-sector
Speech 12.2 kbps	30.88
Packet 64 kbps	7.50
Packet 128 kbps	4.90
Packet 384 kbps	2.30

However, 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.

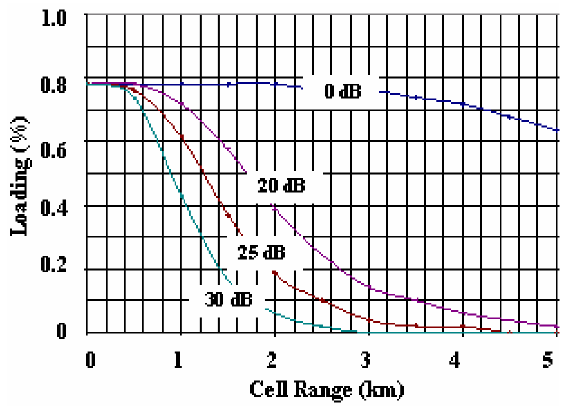

Fig. 1 Simulation results of capacity versus cell range in an urban environment. Each curve corresponds to a certain downlink margin (DL_{marg}) [5].

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

$$DL_{marg} = BL + CPL + BPL + \Delta G_{ant} + L_{f+j} + L_{slant} + L_{TMA} + \Delta N_f + \Delta A_0 \quad (6)$$

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.

BPL is the building penetration loss.

ΔG_{ant} is the difference in antenna gain compared to the value used in the curves: $\Delta G_{ant} = 17.5 - G_{ant}$ where G_{ant} (dBi) is the sum of the BS and the UE antenna gain.

L_{f+j} is the loss in feeders and jumpers.

ΔN_f is the difference in UE noise figure compared to the value used in the curves: $\Delta N_f = N_f - 7$ where N_f is the noise figure of the UE (7 dB recommended).

L_{slant} is the slant loss (1 dB) associated with cross-polarized antennas.

L_{TMA} is the insertion loss of the TMA (if used).

ΔA_0 is the difference of the distance independent term, in Okumura Hata, compared to the value used in the curves: $\Delta A_0 = A_0 - A_{0curves}$, where $A_0 = A - 13.82 \log H_b$ and $A_{0curves}$ is 134.7, H_b = 40 m in this case.

Note: $A_0 = 155.1 - 13.82\log 40 = 133$

Table 6. Margin factors for a high-mobility environment

Margin factor	Level
Body loss (BL)	0 dB
Car penetration loss (CPL)	6 dB
Building penetration loss (BPL)	18 dB
Antenna gain (G_{ant})	18 dBi
Feeder and jumper loss (L_{f+I})	5 dB
Slant loss (L_{slant})	1 dB
TMA insertion loss (L_{TMA})	0.4 dB
UE noise figure (N_f)	7 dB
Antenna height	40 m

All parameters in Table 6 are used to calculate the DL_{marg} by substitute them to Eq. (6). The result is DL_{marg} = 28.2 dB.

The values in Table 5 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 data users (internet users) in an urban environment is calculated at a range of 1.5km.

After calculating the M_{max}, Table 5 shows the M_{max} values of the uplink. Now, the uplink 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 high-mobility (120km/hr) case and at data rate 32 kbps:

(1) In Fig. 1, the relative load at which the curve for DL_{marg} = 28.2 dB crosses the 1.0 km range is found approximately about 50%. This is below the maximum load limit.

(2) The M_{max} value for packet 32 kbps for a three-sector site is found in Table 5 = 13 users.

(3) Finally, the supported relative load is calculated: 13x0.5 ≈ 6 simultaneous users.

Thus, in this specific case, one cell would be able to support approximately 6 simultaneous Internet users at data rate 32 kbps.

Following the same procedure above, the number of simultaneous users for the downlink of a three-sector site can be shown in Table 7. The results in Table 7 reveal that the commercial WCDMA mobile Internet can support the Royal Thai Armed Forces communication systems in high-mobility (120km/hr) for only one station at the multimedia capacity of 384kbps.

Table 7. The number of simultaneous users for omni-drectional and three-sector site configuration with fast fading at 120km/hr.

Service	Simultaneous users Three-sector
Packet 32kbps	6
Packet 64kbps	3
Packet 128kbps	2
Packet 384kbps	1

4. Conclusion

This paper outlines how to calculate the capacity of the WCDMA FDD mobile Internet network. The paper analyzes the capacity of WCDMA-FDD uplink and downlink for mobile Internet networks in the high-mobility environment. The maximum number of simultaneous users of uplink and downlink is calculated at mobile-terminal speed 120km/hr (worst-case scenario). The results reveal that the commercial WCDMA mobile Internet can support the Royal Thai Armed Forces communication systems in high-mobility environment for only one station at the multimedia capacity of 384kbps. It means that the system can be utilized for the commander's vehicle as the central command unit. However, for the future study, the Royal Thai Armed Forces should evaluate this study in the real environment. The methods described in this paper can be used for rough estimates suitable in the dimensioning process and will be a valuable contribution towards mobile Internet system designs.

References

[1] Erik Dahlman et.al. (1998), "WCDMA – The Radio Interface for Future Mobile Multimedia Communications", *IEEE Transaction on Vehicular Technology*, vol. 47, no. 4, pp. 1105-1118. November 1998.
[2] R. De Bernardi, D. Imbeni, L. Vignali, "WCDMA Down-link Power Approximation", *Ericsson Technical paper:* TEI/TRB 00:004.
[3] "Radio Access Network: Radio Transmission and Reception", *3GPP TS* 05.05 v8.14.0, Aug., 2002.
[4] "Evaluation Report for ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT Candidate", *ETSI.*
[5] Ericsson Radio Systems Group, "RF Guidelines WCDMA radio access network", *Ericsson Technical paper*: 9/1151-HSD10102 Rev pA2, 2000.
[6] Ericsson Radio Systems Group, "Coverage and Capacity Calculation", *Ericsson Technical paper*: EN/LZT 123-6039 R1A.
