

# Capacity and Quality Optimization of CDMA Networks

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**Abstract**—Coverage and capacity are important issues in the planning process for cellular third generation (3G) mobile networks. The planning process aims to allow the maximum number of users sending and receiving adequate signal strength in a cell. This paper describes the conceptual expressions require for network coverage and capacity optimization analysis, examines service quality issues, and presents practical solutions to problems common to sub-optimality of CDMA networks.

**Keywords**—CDMA, link pilot, network planning, quality of service.

## 1. Introduction

Development of the third generation (3G) systems, such as code division multiple access (CDMA) – including 2000 series that utilises CDMA as an underlying channel access method-provided connectivity to packet data networks via cellular systems while increasing voice capacity. As one would expect, many of the rapidly growing internet applications and services are finding their way into the mobile wireless domain and taking advantage of the 3G system. Services such as real time streaming video and music, and on-line interactive gaming are just a few examples of services whose popularity is growing beyond expectations. Hence, services of this nature have challenged 3G networks standardization capable of providing increase data throughput. The 3G networks may also be referred to as universal mobile telecommunication system (UMTS) [1].

Spectrum is a valuable and limited resource. Therefore for an operator, cost effective improvement in capacity is always an important goal. Capacity gain, both for voice and new data services, is crucial for an operator's competitiveness. It is possible to achieve significant capacity improvements in existing networks without deploying additional carrier and base stations or drafting new standards. By following proper *radio frequency* (RF) network planning and optimization techniques; CDMA operators would see immediate benefits on their network capacity. CDMA is a digital cellular technology that uses spread-spectrum techniques [2]. It does not assign a specific frequency to each user. Rather, every channel uses the full available spectrum. Individual conversations are encoded with a pseudo-random digital sequence.

The objective of network planning is to maximize the coverage and capacity, and the quality of service. However, in the 3G planning, since all carriers in the network use the same frequency range, frequency planning is not required.

Furthermore, coverage and capacity planning should be performed in tandem since capacity requirement and traffic distribution influence the coverage [3], [4].

## 2. Network Planning

There are three distinct standards operating worldwide for 3G networks namely WCDMA, CDMA2000 and TD-SCDMA, but all have similar planning process as well as overall operational objectives. This planning process can be divided into three parts:

1. Initial phase (also called system dimensioning) involves estimating traffic throughput, coverage area, and coverage threshold.
2. Digital planning phase includes meeting traffic, configuration, coverage threshold and capacity requirements.
3. Radio frequency optimization and monitoring; involving coverage verification and capacity availability.

We see that the whole process of 3G planning needs to take into account coverage and capacity planning. In a cellular system where all the air interface connections operate on the same carrier, the number of simultaneous users directly influences the receivers' noise floors [5]. Consequently, the performance of any digital modulation technique can be described in terms of the normalized ratio of energy per bit ( $E_b$ ) to interference density ( $I_o$ ) required to achieve the minimum desired bit error ratio (BER). The relationship between normalized value and the signal-to-noise ratio over the entire occupied bandwidth ( $S/N$ ) needs to be established ensuring the required minimum or threshold value ( $E_b/I_o$ ) for an acceptable network performance.

### 2.1. Derivation of CDMA Network Coverage and Capacity

CDMA, being a spread spectrum technique, requires that the occupied bandwidth ( $W$ ) to be much greater than the information bit rate,  $R$ . The ratio, ( $W/R$ ) (also known as *processing gain*) then becomes a factor by which ( $E_b/I_o$ ) is improved over the entire occupied bandwidth. The relationship between normalized value and the signal-to-noise ratio ( $S/N$ ) can be expressed as

$$\frac{S}{N} = \frac{E_b}{N_o} \frac{R}{W}. \quad (1)$$

Rearranging to have

$$\frac{E_b}{N_o} = \frac{S}{N} \frac{W}{R}. \quad (2)$$

We assume the system's capacity requirements are inherently the same for uplink and downlink. Strictly, this assumption holds in voice systems when defined by the number of users, and may not be true for data systems; capacity requirements may be asymmetric and would require some subtle modification. The full bandwidth ( $S/N$ ) ratio is the ratio of received power of the desired signal  $P_r$ , to the sum of the noise over the full bandwidth ( $N_o W$ ) and the total interference ( $I_o$ ) including from other users, which can be formalized as:

$$\frac{S}{N} = \frac{P_r}{I_o + N_o W}, \quad (3)$$

where  $N_o$  is the total floor noise or thermal noise.

For  $k$  users per channel occupying the same spectrum, the "same cell" interference power  $I_{usc}$  is

$$I_{usc} = (k-1)P_r,$$

while "adjacent cell" interference  $I_{uad}$  is equivalent to the "same cell" interference but modified by *loading factor*,  $\eta$ . That is

$$I_{uad} = \eta I_{usc} = \eta(k-1)P_r. \quad (4a)$$

The loading factor is proportional to frequency reuse,  $f_r$ , which is the ratio of total interference to own cell interference; that is,

$$f_r = \frac{1}{1 + \eta}. \quad (4b)$$

Adding interferences from "same cell" and "adjacent cell" and taking into consideration interference reduction achieved through transmission – muting during voice pauses and sectionalizing – we can write expression for total interference:

$$I_o = \frac{G_v G_s (k-1)}{f_r} P_r, \quad (5)$$

where  $G_v$ , and  $G_s$  are scaling factors, i.e., voice gain and section gain respectively. In view of Eq. (5) in Eq. (3), we have

$$\frac{S}{N} = \frac{P_r}{\left( \frac{G_v G_s (k-1) P_r}{f_r} + N_o W \right)}. \quad (6)$$

Given a digital modulation technique, we can define  $\gamma_t$  as the minimum or threshold value of ( $E_b/I_o$ ) required for an acceptable network performance. As a result, Eq. (2) must be greater than  $\gamma_t$ . So, Eq. (6) in Eq. (2) and applying threshold, the desired signal

$$P_r > \frac{\gamma_t N_o W}{\frac{W}{R} - \frac{\gamma_t G_s G_v (k-1)}{f_r}}. \quad (7)$$

This equation can be used to demonstrate the dependency of received signal on the user data rates,  $R$ , and the total number of active users in a cell. The terrain under which

a user operates and the user's proximity to the base station affect the effective power received by user's mobile devices (i.e., *mobile station*, MS). Suppose an MS is at distance  $d$  from the *base transceiver station*, BTS. The received power at the BTS,  $P_{r(BTS)}$ , from MS, can be expressed as

$$P_{r(BTS)} = P_{t(MS)} - PL(d) - z. \quad (8)$$

where:

- $P_{r(BTS)} = P_r$  is the power received by BTS (in dBm),
- $P_{t(MS)}$  is the transmission power of the MS (in dBm),
- the propagation loss at distance  $d$  from the MS to BTS (in dB).
- $z$  is error due to shadow fading (in dB), where motion of the mobile results in variation of the received signal strength.

This presupposes that network coverage is limited by the maximum transmission power at the mobile and no blocking nor outage takes place in the cellular system (since CDMA technology can provide the enough codes for the new call to the cell in the ideal situation).

We ignore here fast shadow fading. A statistical model [6] can be used to generate correlated shadow-fading patterns in the absence of detailed propagation and landscape information, or cross-correlation function model [7], or a simple power lognormal distribution.

In the cellular situation, it is impossible to apply the free-space loss rule because of the proximity of the earth and the effects of trees, building, and hills in, or close to, the transmission path. The propagation loss  $PL(d)$  is modeled on the Okumura-Hata [8] path prediction model. The basic equation for path loss (in dB) is

$$PL(d) = 69.55 + 26.16 \log f - 13.82 \log h_{BTS} + [44.9 - 6.55 \log h_{BTS}] \log d - a(h_{MS}) + C, \quad (9)$$

where:  $f$  is the transmission frequency (in MHz);  $h_{BTS}$  is base transceiver station antenna height (in m);  $h_{MS}$  is mobile station antenna height (in m);  $C$  and  $a(h_{MS})$  are correction factors whose values depend on the propagation terrain's type and height.

For medium to large cities,  $C = 0$ . Like all empirical models, the Okumura-Hata model can be adjusted for specific propagation terrains and then use experimentally acquired correction factors to reduce their uncertainty. We can now build a relationship among the received power, number of users, the coverage area or terrain, and other essential parameters drawing from Eqs. (7), (8) and (9):

$$P_{r(BTS)} = P_{r(MS)} - PL(d) - z = 10 \log \left[ \frac{\gamma_t N_o W}{\frac{W}{R} - \frac{\gamma_t G_s G_v (k-1)}{f_r}} \right]. \quad (10)$$

The equations can be used in cellular system planning to set hard limits on the maximum number of users that can

be admitted into the cell. Identifying and analyzing these relationships can achieve effective planning in designing cell capacity and coverage to matching specified data services.

## 2.2. Capacity Improvements with Optimization

Theoretically, we can obtain the maximum capacity ( $k_{\max}$ , also called *pole capacity*) by equating the denominator of the logarithm argument of Eq. (10) to zero. That is,

$$\frac{W}{R} - \frac{\gamma_v G_v G_s (k-1)}{f_r} = 0 \quad (11a)$$

giving the pole capacity

$$k_{\max} = 1 + \frac{f_r \left( \frac{W}{R} \right)}{\gamma_v G_v G_s}. \quad (11b)$$

Naturally, this maximum capacity implies that receive power goes to infinity and/or coverage shrinking to zero. In reality, this is unrealistic due to signal-quality constraints in uplink and downlink directions, applicable power control mechanism, and pilot signaling.

Network optimization is an integral part of the operation and maintenance of mobile networks. It is often performed whenever there is a change in the network. Proper optimization techniques enable the network operator to fine-tune the network for maximum attainable capacities. The next subsection covers the important steps required in network optimization process to achieving improvements in network capacity and guarantee superior quality of service.

## 2.3. RF Network Planning and Optimization

Most CDMA networks that suffer from RF capacity degradation are the result of poor RF network planning and optimization. An optimized RF environment is vital for operators seeking to maximize capacity. Figure 1 illustrates the relationship between base transceiver station (BTS Tx) power reductions and combined forward link pilot – i.e., the ratio of the average power of a channel,  $E_c/I_o$  – under different forward link loading scenarios. The figure shows that for higher combined  $E_c/I_o$ , lower traffic channel ( $E_c/I_{or}$ ) is required and more BTS *high power amplifier* (HPA) power is conserved to accommodate more users in the same sector. Typically, as shown in Fig. 1, a 1 dB BTS Tx power reduction for each voice channel increases RF capacity by approximately 15% for any given BTS sector. In essence, to achieve a uniform service quality is provided to all channels, transmission power of the forward traffic channel would need to be controlled by base stations according to the pilot powers measured at the respective mobile stations.

We see that in CDMA systems, coverage and capacity are heavily coupled and cannot be planned separately such as they could in the second-generation (2G) systems. The expression given by Eq. (10) describing the relationship between coverage, capacity and data rates is very useful in planning the networks. However, there are shortcomings

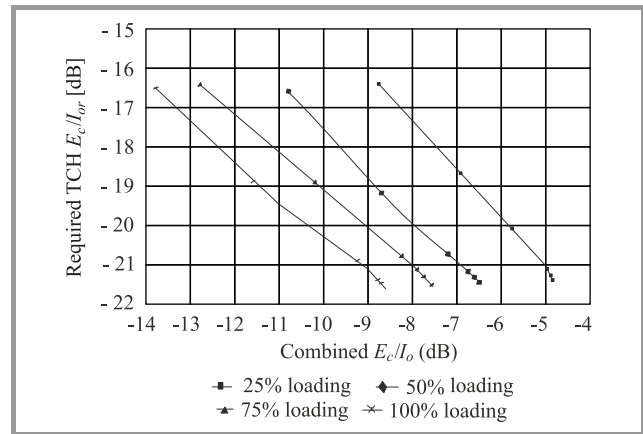


Fig. 1. BTS Tx power reduction versus combined  $E_c/I_o$ .

in the analysis and modeling provided herein. The modeling is largely based upon an ideal situation, wherein no call will be blocked. While CDMA technology can itself provide enough codes for the mobile terminals to assure the ideal situation (enough for every user, therefore there is no blocked call) these are not used in practice. To overcome the shortcomings of the modeling presented herein, in future work we would need to consider the outage probability and dynamic loading control in the planning process and minimizing costs.

### 2.3.1. Capacity Improvement Areas

Problems common to sub-optimality of CDMA network having RF capacity issues and solutions include:

- **Forward/reverse link imbalance** – this problem is normally caused by boomer sites with elevated antenna radiation centres. The BTS forward link covers distant areas or deep inside buildings where the reverse link of a mobile cannot reach back to the base station. In this case, excessive forward link traffic channel power is always allocated to compensate for the path loss. Link imbalance areas typically can be identified if the forward link coverage is sufficient (good pilot  $E_c/I_o$ ) but call setup failure is high due to exhausted mobile transmit power on the reverse link. Link imbalance can be identified by drive testing into problematic areas or analyzing the network performance data for problematic clusters / sectors. RF coverage on the forward link is much larger than that on reverse link; excessive BTS Tx power is allocated for the remote user. Primarily involves making decisions on where to install new base stations and how to select their configuration, including antenna height and tilt, sector orientations, maximum emission power, pilot signal [9].
- **Excessive soft handoff area** – caused by improper cell site layout, misuse of base station antennas. This may require reduction of excessive handoff areas. In a well optimized, lightly loaded CDMA network, the typical soft handoff reduction factor is be-

tween 1.6 and 1.8; this range is reduced to 1.4 to 1.6 for a loaded network. If a higher value is seen in some areas of the network, this could indicate that those areas have softer handoff than necessary. Soft handoff increases the reliability of the radio link, but the base station requires more power to maintain the soft handoff, which reduces the forward link capacity.

- **Improper RF parameter settings** – RF parameter settings should be fine-tuned according to the traffic loading distribution in order to improve the overall network performance. RF parameter adjustments could be considered after the RF environment has been optimized and the network has reached a stable stage. There are no fixed rules on parameter changes. When voice capacity enhancement is the objective, some channel power management and power control parameter can be considered for the tuning. Nevertheless, base station’s transmitter HPA power limits forward link capacity. Forward overhead channels and traffic channels share the HPA power: depends on the individual base station products.

### 3. Conclusion

Efficient planning and optimization of mobile networks is key to guaranteeing superior quality of service and user experience. This paper has developed expressions that can be used for detailed analysis of the criterion of optimization, as well as for network planning. CDMA network operators have various solutions, both short term and long term, to enhance their system capacity. Anomalies such as forward/reverse link imbalance, excessive soft handoff areas, and improper RF parameter settings could lead to under utilization of system capacity. This paper has also explained that with proper network planning and network optimization of the installed CDMA network, operators can quickly and efficiently utilize their network resources to achieve optimum system capacity.

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