Coverage and Capacity Calculations for 3G Mobile Network Planning

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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. In this paper we present calculations for capacity, coverage for 3G networks.

Key Words: *3G, CDMA, planning, coverage, capacity.*

1. INTRODUCTION

Third Generation (3G) radio networks are based on the code division multiple access technology (CDMA) and are currently being installed in countries such as Japan and South Korea. The aim of the technology is to fulfil the user requirement for innovative services such as enhanced and multimedia messaging through high-speed data channels. CDMA is a digital cellular technology that uses spread-spectrum techniques. 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. Third Generation networks may also be referred to as Universal Mobile Communication Telecommunication System (UMTS), see [1], for example. There are three standards accepted by International Telecommunication Union (ITU). They are Wide-band CDMA (WCDMA), CDMA2000 and time-division synchronous CDMA (TD-SCDMA).

Due to the high costs and the scarcity of radio resources, an accurate and efficient mobile network planning procedure is required. The objective of network planning is to maximise the (usually conflicting goals of) coverage, capacity and the quality of service.

The structure of the paper is organised as follows: Section 2 describes the background of planning for radio networks, concentrating on second generation (2G) technologies. The issues for 3G network planning are covered in Section 3. Relationships between coverage and capacity are given before the concluding comments of Section 4.

2. BACKGROUND

The planning of 3G is very different from the Second 2G which adopts a time division multiple access technology (TDMA). TDMA works by dividing a radio frequency into time slots and then allocating slots to multiple calls. In this way, a single frequency can support multiple, simultaneous data channels.

2G planning can be divided into a coverage planning phase and a frequency planning phase which are driven by coverage and capacity criteria respectively. In the coverage planning phase, base stations (BSs) are placed so that the signal strength is high enough in the area to be served. In the frequency-planning phase, each BS is assigned a number of channels, then network operator takes into account the traffic load, the level of services measures as the signal-to-interference ratio (SIR) as well.

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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.

Although there are three distinct standards in 3G networks (each used in different parts of the world), WCDMA, CDMA2000 and TD-SCDMA, the general planning process and overall objectives are the same.

3. 3G RADIO NWETWORK PLANNING

The 3G planning process can be divided into three parts; the initial phase (also called system dimension); detailed planning phase; and the optimisation and monitoring phase. Each of the phases requires additional considerations such as propagation measurements, traffic demand measurements and so on. The process of the 3G planning is illustrated in Figure1.

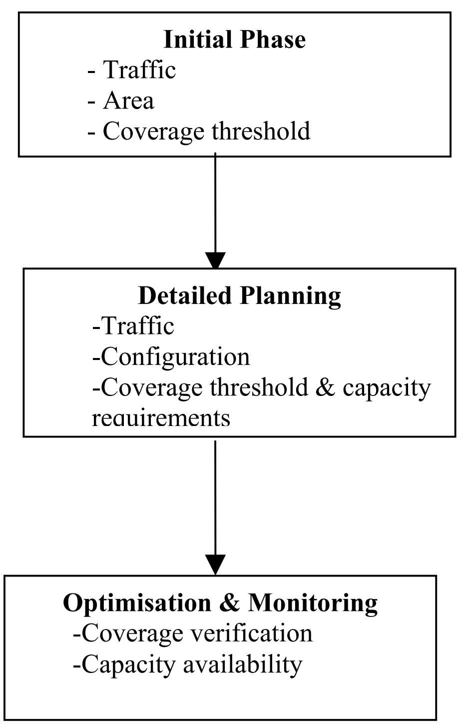

Figure1. 3G system planning process

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 is directly influences the receivers' noise floors.

It is well known that the coverage of the cell has an inverse relationship with the user capacity of the same cell. An increase in the number of active users in the cell causes the total interference seen at the receiver to increase. This causes an increase in the power required to be received from each user. This is due to the fact that each user has to maintain a certain Signal-to-Interference Ratio (SIR) at the receiver for satisfactory performance. For a given maximum allowable transmission power, an increase in the required power reception will result in a decrease in the maximum distance a mobile can be from the base station thereby reducing the coverage.

We will consider the up-link and the ideal situation of the CDMA technology. That is to say, we will assume the coverage is limited by the maximum transmit power at the mobile and no blocking and outage take place in the cellular system since CDMA technology can provide the enough codes for the new call to the cell in the ideal situation.

3.1 Initial Model for Capacity Calculation

We first attempt to calculate the maximum number of users in a particular cell. This is based on a static capacity calculation and the following assumptions are made:

1. Each cell is completely isolated. That is, there is no inter-cell interference.
2. Signals from mobile stations cause no interference within the cell. That is, there is no intra-cell interference.
3. There is perfect power control from the base station. That is, all signals arrive at the base station with equal power.
4. There is no limit to the number of spreading codes available.

The actual capacity of a CDMA cell depends on many different factors, such as power control accuracy, interference power. We begin by calculating the signal-to-interference ratio. If there are N users in a cell and the signal is denoted by S then the interference can be calculated as $I = (N - 1) S + \eta$, where η is the thermal noise. Hence the SIR is given by

$$SIR = \frac{S}{(N-1)S + \eta} = \frac{1}{(N-1) + \eta / S} \quad (1)$$

The value of the interference is based upon the four assumptions above and is not realistic. For this work we only use this value since other factors are small in our situation. Other interference factors are known as inter-cell and intra-cell interference. The inter-cell interference is attributed to mobile stations and base stations in one cell affecting the operations in another. This is results in unwanted noise. Intra-cell interference can be attributed to the effect one mobile station has on the transmitted signal of another within the same cell. It is s simple step to change the interference value to consider the other two factors though in this paper it would only serve to complicate the formulae.

Suppose the digital demodulator for each users can operate against the noise at an energy per bit-to noise power density level is given by E_b / I_o, where $E_b = S / R$ and $I_o = I / W$.

$$\frac{E_b}{I_o} = \frac{S/R}{I/W} = SIR\frac{W}{R} \quad (2)$$

Here W is the chip rate and R is rate of data communication.

Hence using (1) and (2) we can obtain

$$(N-1) = \frac{W/R}{E_b/I_o} - \eta / S \quad (3)$$

In particular, if the user is not speaking during part of the conversation, the output of the coder is lowered to prevent the power from being transmitted unnecessarily. For a uniform population, this reduces the average signal power of all users and consequently the interference received by each user. The capacity is then increased proportional to this overall rate reduction, provide. Speech statistics shows that a user in a conversation typically speaks close to 38% of the time. the effects of voice activity and sectorization should be considered. This results in an increase in the $\frac{E_b}{I_o}$ by a voice activity gain factor, G_v. Similarly, the sectionsation gain factor G_s also increases the $\frac{E_b}{I_o}$ and the equation for the effective number of users, N_ε, becomes

$$(N_\varepsilon - 1) = G_v G_s \left(\frac{W/R}{E_b/I_o} - \eta / S\right) \quad (4)$$

Using speech statistics we can set G_v =2.63 and based upon the usual three sectors for a cell, G_s =2.63. $\frac{W/R}{E_b/I_o}$ is typically a value between 20 to 100.

Finally, for a cellular system in which all users in all cells employ the common spectral allocation of W Hz, we must evaluate the interference. Normally the total interference equal the amount of interference from other cells and interference from given cells.

We define:

f=(interference from other cells)/(interference from given cell)

Due to the interference, the actual numbers of user will decrease from $(N\varepsilon - 1)$ to $(N_\phi - 1)$ (Ref.[7]), the equation (4) will be modified into (4.1)

$$N_\phi - 1 = G_v G_s \left(\frac{W/R}{E_b/I_o} - \eta / S\right)\frac{1}{1+f} \quad (5)$$

Normally, the total interference from users in all other cells equals approximately three-fifths of that caused by all users in the given cell. (See [9], for example). That is to say, $1 + f \approx 1.6$

However we note that equation (5) gives a poor estimate to N_ϕ due to the many assumptions in the model. It does not reflect the relationship between the capacity and the coverage.

3.2 Coverage Versus Capacity

The analysis in the above we isolate the capacity calculation from coverage. However, in the 3G networks, it is important to derive the relationship between the coverage and capacity.

We will consider the up-link and the ideal situation of the CDMA technology. That is to say, we will assume the 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).

Based on (5), we can understand the performance of a CDMA network by developing a simple expression for the ratio E_b / I_o, as follows.

$$\frac{E_b}{I_o} = \frac{\frac{S}{R}}{\frac{(N_\phi - 1)S(1+f)/GvGs + \eta}{W}} \qquad (6)$$

Solving the equation (6) for S gives:

$$S = \frac{\frac{E_b}{I_o} R\,\eta}{W - (\frac{E_b}{N_o} R(N_\phi - 1)(1+f))/GvGs} \qquad (7)$$

This equation can be used to demonstrate the dependency of S on the user data rates, R, the voice and section gain G_v, G_s, respectively, and the total number of active users in a cell, N_ϕ.

We focus on the coverage by user1 when the number of users in the cell is N_ϕ. Let *r* be the distance of user1 from the base station. The received power at the base station from mobile user1, S, is given by

$$S = S_1 - P(d) - Z \qquad (8)$$

Where

S_1 : The transmission power of the user.

$P(d)$: The propagation loss at distance d from the MS to BS.

Z : The shadow fading

The propagation loss is usually calculated by using propagation models. The propagation model that is most commonly used is the Okumura-Hata. The model is developed by combining propagation theory and extensive measurement campaigns. The model considers several parameters such as effective antenna height, terrain type, terrain height, frequency, and so on. For details of the Okumura-Hata model the reader is referred to [2]. The model predicts

$$P(d) = A + B\log_{10} f - 13.82\log_{10} h_{BTS} - a(h_{ms}) + (44.9 - 6.55\log_{10} h_{bts})\log_{10} d + C_m$$

Where *A*, *B* are constants defined by the frequency and *f* is the frequency. $a(h_{ms})$ is a function that depends upon the height of the mobile station that is particular to the environment. C_m is the area type correction factor.

For simply the questions, the propagation loss and the distance relationship can be expressed as

$$P(d) = p_1 + p_2 \log_{10} d \qquad (9)$$

We can now build a relationship among the received power, number of users, the coverage area, the gain of voice and gain of sectionsation based on equations (7), (8), (9).

$$S = S_1 - (p_1 + p_2 \log_{10} d) - z = \frac{\frac{E_b}{I_o} R\,\eta}{W - (\frac{E_b}{N_o} R(N_\phi - 1)(1+f))/GvGs} \qquad (10)$$

4. CONCLUSION AND FUTURE WORK

The efficient network planning is a vital aspect of 3G networks. Key differences arise between 2G and 3G networks due to the different levels of service offered. By identifying and analysing the relationships between capacity, coverage and quality of service.

The equations derived in this work can be used in cellular system planning to set hard limits on the maximum number of users that can be admitted into the cell. For example, the pre-specified coverage requirements are met. It is also useful in planning a cellular network to design cell coverage and capacities to match specified data services, such as 9.6Kb/s, 144Kb/s etc.

Capacity issues for CDMA cellular systems play a vital role in network planning. We see that in CDMA systems, coverage and capacity are heavily coupled and can not be planned separately such as they could in 2G systems.

The relationship given in (10) describing the relationship between coverage, capacity and data rates is very useful in planning the networks.

However, there are shortcomings in the analysis and modelling provided herein. The modelling 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. In application the network operators take into account the cost of equipment (which is related to the number of codes used) and the network load. They use Erlang B to assure certain grade of service.

To overcome the shortcomings of the modelling presented herein, in future work we would need to consider the outage probability and the loading control in the planning process. An analysis considering outage probability and cell loading will give a more accurate relationship between the coverage and capacity.

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