The Reverse Link Capacity of WCDMA Cellular System by Using Repeater +

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Abstract

Some studies have been done on capacity of a Wideband Code Division Multiple Access (WCDMA) cellular system using repeater. But no one has been focused in detail on the capacity of the WCDMA reverse link cellular repeater.

In this research, the use of repeater in a WCDMA cellular system containing hotspot (highly loaded area within an otherwise homogeneously loaded network) is studied. The simulation is achieved through Matlab.

A very important results obtained, shows the benefits of using the repeater in a cell having a hotspot, i.e., increasing the capacity (the number of users). The results show that repeater has very good effect on the reverse link capacity of the WCDMA cellular system. The link capacity is calculated with respect to two variables, the mobile power and E_b/I and compared with that of the link without repeater. The results show that repeater has very good effect on the reverse link capacity of the WCDMA cellular system. Hence, we obtain an improvement in the system capacity by about (11-53) % compared to when no repeater is used

المستخلص

تم إنجاز بعض الدراساتِ على سعة (عدد المستخدمين أو المشتركين) للنظامِ الخلوي *WCDMA* باستخدام المكرر . ولكن لا توجد دراسة رُكِّزت بالتفصيلَ على سعة النظامِ الخلوي *WCDMA* (الوصلةِ العكسيةِ) باستخدام المكرر .

في هذا البحث، تمت دراسة استعمال المكرّر في النظامِ الخلوي **WCDMA** الذي يَحتوي على ما يسمى بالبقعة الساخنة (منطقة مكتظة جداً بالمستخدمين ضمن شبكةِ خلوية متجانسة) . وتم إنجاز الدراسة باستخدام الـ **Matlab**. تم الحصول على نَتائِج مهمة جداً، تبين الفوائد لاستعمال المكرّر في خلية خلوية فيها بقعة ساخنة، وبمعنى آخر ، زيادة السعة (عدد المستعملين). وقد تم حساب السعة بالنسبة لمتغيرين هما قدرة الجهاز المحمول و الـ E_b/I ومقارنتها مع سعة الوصلة من دون مكرر. إذ تم الحصول على سعة اكبر باستخدام المكرر،

1. Introduction

The goal for the third generation of mobile communications system is to seamlessly provide a wide variety of communication services to anybody, anywhere, anytime. The intended service for next generation mobile phone users includes services like transmitting high speed data, video and multimedia traffic as well as voice signals. The technology needed to tackle the challenges to make these services

+ Received on 20/10/2005 , Accepted on 24/5/2007
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available is popularly known as the Third Generation (3G) Cellular Systems. The Wideband Code Division Multiple Access (WCDMA) is one of the 3G cellular systems [1].

Cellular repeaters are used to fill coverage dead-spots that occur due to natural or artificial terrain limitations within the cell or to extend a cell's coverage area while avoiding the prohibitive cost and time of adding another Base Transceiver Station (BTS).

Most cellular repeaters operate in an "on-frequency" manner by receiving and transmitting at the same frequency [2].

A repeater is a bidirectional amplifier used to extend or augment the coverage from a WCDMA sector [3].

In this paper an attempt is mad to study and analyze the reverse link (from mobile to base station) capacity in WCDMA cellular system with the use of repeater inside the cell.

2. Wideband CDMA (WCDMA)

WCDMA is a broadband direct sequence code division multiple access (DS-CDMA) system. It means that user information bits are spread over a wide bandwidth by multiplying them with random bits. The maximum user bit rate will be about 2Mbps. The chip rate of 3.84 Mcps used leads to a carrier bandwidth of approximately 5 MHz. As WCDMA is wide carrier bandwidth it supports high user data rates and also has certain performance benefits, such as increased multipath diversity. It supports highly variable data rates, in other words the concept of obtaining Bandwidth on demand is well supported. It also supports two main modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, separate 5 MHz carrier frequencies are used for the uplink and downlink respectively, whereas in TDD only one 5 MHz is time shared between uplink and downlink.

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One of the important quantities of a CDMA system is the processing gain $G=W/R$, which is the ability to suppress noise and interference relative to the desired signal [4,5].

3. The WCDMA Cellular Repeater

A repeater is a device that is situated in between a base station and a mobile station. It has two antennas, one directed towards the base station (typically line of sight) and one directed towards a service area. It amplifies received signals and retransmits them in both up and downlink with a delay of a few microseconds. Repeaters may be used for different purposes. The most classical application is to increase the coverage area for a base station, e.g. for coverage in a tunnel. It can, however, also be used to decrease interference in the system, since mobiles communicating via the repeater need a lower output power than without the repeater. The repeater can also solve the problem of hot spot inside the cell [5].

4. Problem Definition

There are some works on repeaters in many literatures for various purposes, but nothing on analyzing the capacity of the reverse link in WCDMA cellular system when repeaters used in usual base station systems when there are some circular hotspots within the normal cell. The task of this work is to introduce hotspot in the cell and compare various results in addition to the capacity with and without repeater. The comparison will be done in terms of many factors present in the system. Also, we have made some assumptions during the derivation of the number of user accommodated in the system. These are:

1. There are M mobiles that are transmitting at a given time in a cell.
2. It is assumed a perfect power control on the reverse link.
3. The signals transmitted from all mobiles arrive at the base station with the same received power. Also, at the cell size, we have $P_R >> P_M$.

The location of the hot spot and the repeater are shown in Figure (1).

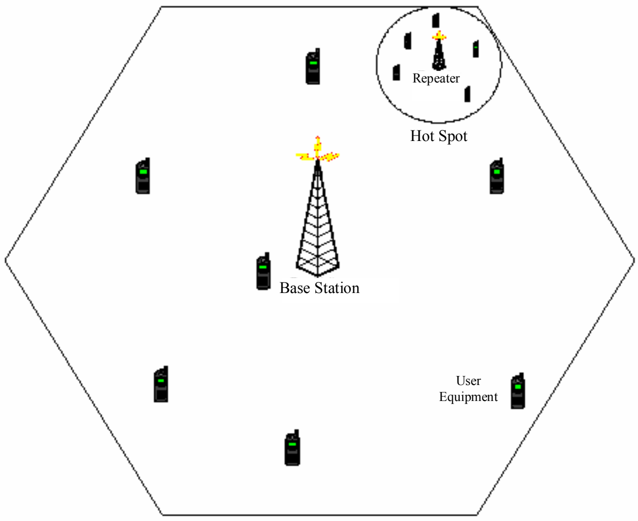

Figure 1 : A hotspot in a cell

As shown in the above figure, we have a cell with a hexagonal shaped with base station in the middle of the cell. The circular area at the internal edge of the cell is the hot spot with increased traffic loads are introduced within it. The repeater is shown in the middle of the hot spot.

When a repeater is used in the hotspot, there are no obstacles between the base-station and the mobile. Our reverse link model is shown below. In this case the base station receives the sum of two signals as illustrated in Figure (2) which is the considered scenario.

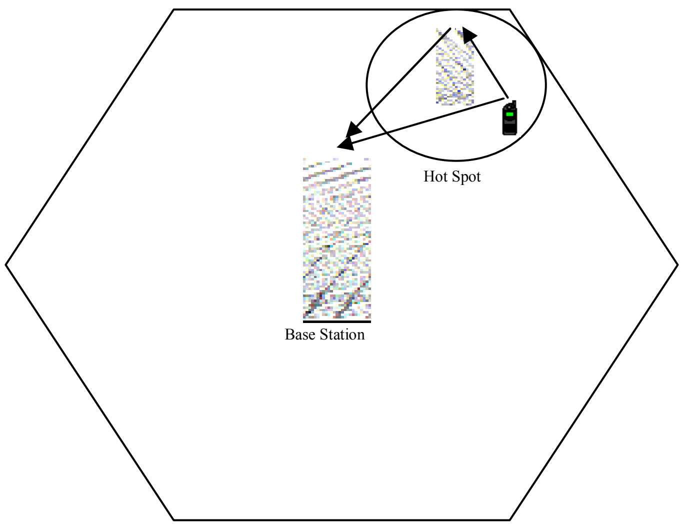

Figure 2 : Mobile station connection with Repeater and Base station

5. WCDMA Reverse Link Capacity without Repeater

We assume that interference at that cell site by mobiles in the access mode is typically too small to worry about - it can be accounted for as a source of some degradation in system quality and system capacity. We force only on the active mobiles in our analysis. We assume there are *M* mobiles that are transmitting at a given time in a cell. In a WCDMA environment, for each mobile, there is (M-1) co-channel interference.

Then the number of user accommodated in WCDMA reverse link i.e., the WCDMA capacity is [6]:

$$M = 1 + G_p\left[\frac{1}{(Eb/I_t).v_f}\right] - \frac{N_o.B_w}{S_r.V_f} \quad \ldots\ldots (1)$$

where:

$$S_r = P_m + G_m + G_b + G_{dv} + L_p \quad \ldots\ldots (2)$$

where:

S_r : the average signal power received from the ith mobiles.
R : mobiles transmission rate in bps.
v_f : voice activity factor.
G_p : processing gain = B_w /R.
G_m : transmit antenna gain of the mobiles.
G_b : receiver antenna gain of base station.
G_{dv} : base station antenna diversity.
L_p : path loss.
P_m : transmit power of mobiles.

6. WCDMA Reverse Link Capacity with Repeater

At the cell size, the average signal power received from the ith mobile is P_{Mi}, and the average power received from the repeater for the same ith mobile is P_{Ri} . The base station receives the sum of two signals.

Therefore, the total received power at the base station is:-

$$S_{ri} = P_{Mi} + P_{Ri} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

We know that P_{Mi} is given by:

$$\mathrm{P_{Mi}} = \mathrm{P_m} + \mathrm{G_m} + \mathrm{G_b} + \mathrm{G_{dv}} + \mathrm{L_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and P_{Ri} is given by [5]:

$$P_{Ri} = \frac{P_m}{\eta_1} G_{bs} A_r G_{rep} \frac{1}{\eta_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Here, A_r is the repeater amplifier gain, G_{rep} the combined antenna gain for the two repeater antennas, G_{bs} the base station antenna gain, η_1 the path loss from base station to repeater, and η_2 the path loss from repeater to the mobile station.

The thermal noise power is N_oB_w, where ($N_o=KT_e$) is the thermal noise power spectral density, K is Boltzmann's constant, $T_e=T(F-1)$ is the receiver noise temperature, T is the ambient temperature, F is the receiver noise figure, and B_w is the spreading bandwidth. The average co-channel interference at the base station is given as [6]:-

$$I_o = \frac{1}{B_w} \sum_{i=1}^{M-1} v_f . S_{ri} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$I_o = \frac{1}{B_w} \sum_{i=1}^{M-1} v_f . (P_{Mi} + P_{Ri}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where v_f is the voice activity factor.

In the above equation a perfect power control on the reverse link is assumed, and the signals transmitted from all mobiles arrive at the base station with the same received power; in other words, $P_{Mi} = P_M$ for all values of i. This is a very important assumption, hence; we know that each user in the cell has a specific transmitted power arrive at the base station due to its place and surrounding obstacles. However, these variables powers need a power control algorithm in the base station, and this algorithm is out of the scope of our research. So, for this reason and in order to simplify our analysis, we assume that $P_{Mi} = P_M$ for all values of i.

Also, the signals transmitted from all mobiles through the repeater arrive at the base station with the same received power; in other words, $P_{Ri} = P_R$ for all values of i. Then:

$$I_o = \frac{(M-1).v_f.(P_M + P_R)}{B_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The total interference and thermal noise will be:

$$I = I_o + N_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$I = \frac{(M-1).v_f.(P_M + P_R)}{B_w} + N_o \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Another assumption we made, that is $P_R >> P_M$, so, the above equation will be:

$$I = \frac{(M-1).v_f.P_R}{B_w} + N_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

E_b/I will be given as:

$$\frac{E_b}{I} = G_p \cdot \frac{P_R}{\left[N_o B_w + (M-1).v_f.P_R\right]} \quad \ldots\ldots\ldots\ldots\ldots (12)$$

Solving the above equation for M, we get:

$$M = 1 + G_p\left[\frac{1}{(E_b/I).v_f}\right] - \frac{N_o.B_w}{P_R.V_f} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

7. Simulation Results

This section presents the results of capacity (no. of channels) simulations which were performed in Matlab to compare the performance of the WCDMA cellular system with and without repeater. Note that, it is also possible to perform the analysis using any powerful computer language such as C^{++}.

There are some important parameters we used for the simulations are shown in Table(1) below:

Table 1 : The parameters used in the simulation

B_w	R	v_f	T	F
5 MHz	*9600 b/s*	*1*	*290 K*	*5 dB*

Figures (3) and (4) display capacity as a function of mobile power (P_m), with E_b/I = 7 and 8. The capacity improvement is significantly larger in the case with repeater than the case without repeater, due to the improvements in the overall gains of the system. But it should be noticed, that the capacities increase more slowly with P_m.

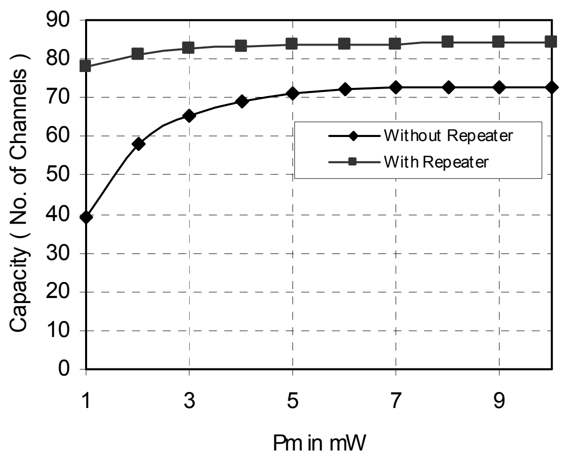

Figure 3: *The capacity with and without repeater for E_b/I = 7*

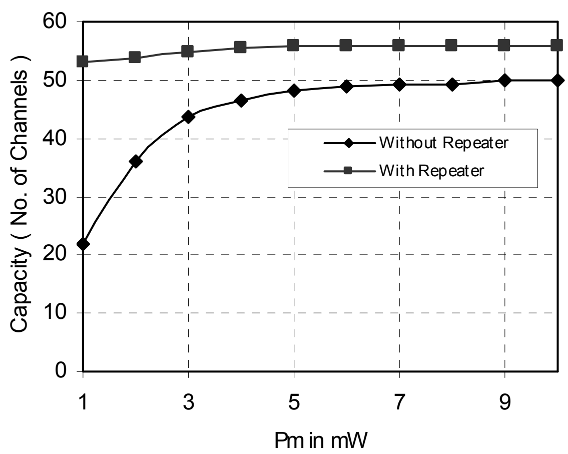

Figure 4: *The capacity with and without repeater for E_b/I = 8*

We now examine the capacity performance as the mobile power becomes very large (i.e., goes to infinity).

By returning to eq. 13, if we take the limit as P_R goes to infinity, we can get the maximum number of users, i.e:

$$M_{\max} = 1 + \left[\frac{G_p}{(E_b / I).v_f} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (14)$$

The repeater performance in this case is not active. See Figure (5) for $E_b/I = 7$.

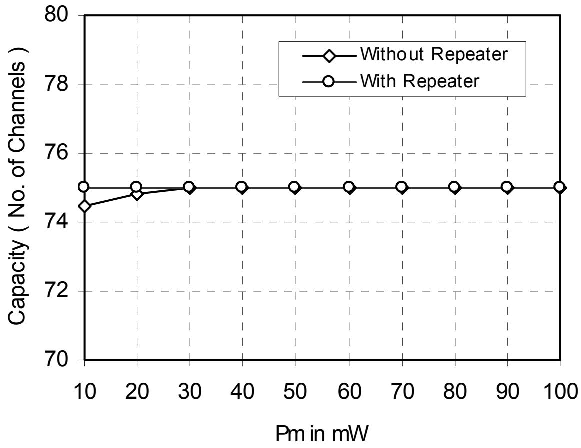

Figure 5: *The capacity with and without repeater for $E_b/I = 7$ and $P_R = \infty$*

Another comparison has been done to show the performance of the WCDMA cellular repeater. Figures(6 and 7) compare the performance of the system with and without repeater, in terms of the capacity with respect to E_b/I. P_m will be kept constant for certain values. It is observe that the capacity is decreased in both cases, but the capacity with repeater is still larger than that of without repeater.

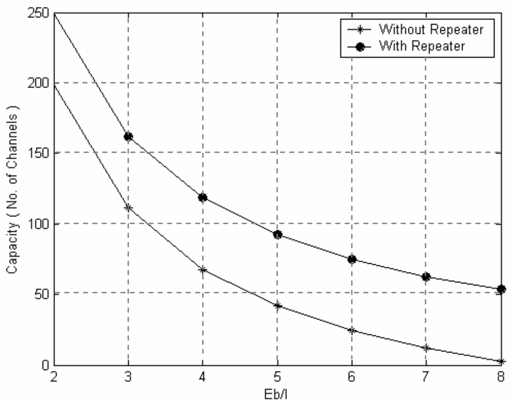

Figure 6: The capacity with and without repeater for Pm = 3 mW

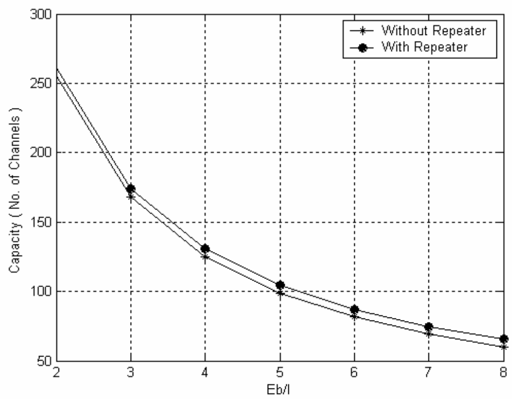

Figure 7: The capacity with and without repeater for Pm = 7 mW

Figure(8) displays the capacity comparison when $P_m = \infty$. As it is notice from the figure, these is no difference between the capacities in both cases. Hence, the power which arrives from the mobile at the base station is (P_m), and that of mobile at the base station with repeater is ($P_m + P_R$). So, when P_m goes to infinity in both cases, the power arriving at the base station will be the same. In other words, Figure 8 is the graph of Eq. 14.

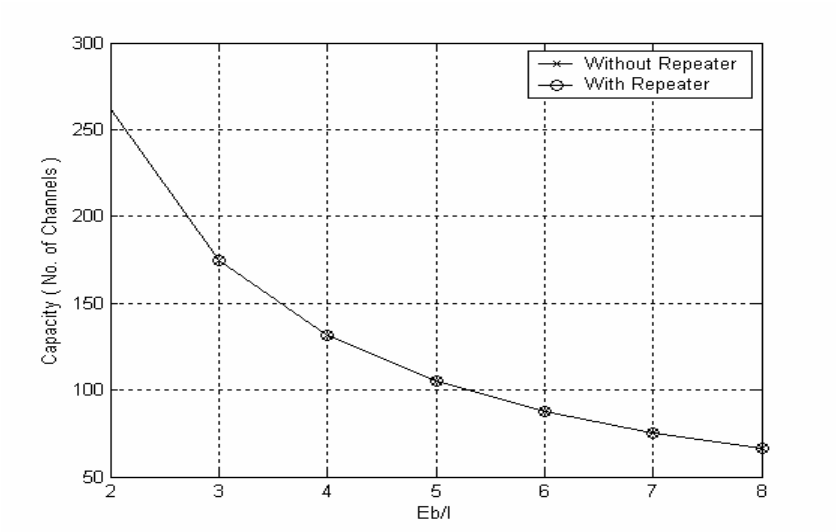

Figure 8: The capacity with and without repeater for Pm = ∞

8. Conclusions

In this paper, WCDMA system with hotspot was studied. Repeaters are viable additions to a WCDMA network. The network performance with and without repeater located in the hotspot is compared in order to investigate whether repeaters are useful in such scenarios or not.

The comparison factor is the capacity with respect to mobile power P_m and E_b/I, and is implemented and obtained by using Matlab. The results show that repeater has very good effect on the reverse link capacity of the WCDMA cellular system. They improve the system capacity by about (11-53) % compared to when no repeater is used depending on the values of the mobile power P_m and the E_b/I ratio.

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