The Impact of Imperfect Power Control and Multiuser Detection on the Uplink of a WCDMA High Altitude Platform System

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***Abstract*— Within the broad field of communications, considerable interest has been drawn towards High Altitude Platforms (HAPs) the past few years owing to their appealing features. Among the multitude of services that HAP systems are able to provide, HAPs have the potential to deliver 3G communication services. In this letter, we examine the impact of both imperfect power control and multiuser detection (MUD) on the uplink of a WCDMA HAP system.**

***Index Terms*— HAPs, WCDMA, power control, multiuser detection.**

I. INTRODUCTION

IN parallel with terrestrial and satellite wireless networks, a new alternative based on platforms located in the stratosphere has recently emerged, often dubbed as High Altitude Platforms (HAPs). HAPs are either airships or aircraft positioned between 17 and 22 km above the earth surface, and due to their unique position they have the potential to deliver a wide spectrum of applications to both mobile and fixed users over a broad coverage area [1]. Among the compelling range of services that HAP systems can provide, HAPs can serve as base stations of 3G networks as well.

Wideband code division multiple access (WCDMA) has emerged as the mainstream air interface solution for 3G networks (UMTS, IMT-2000) and the ITU has specifically authorized the use of some IMT-2000 (3G) frequency bands from HAPs [2]. In spite of the vast literature on terrestrial CDMA cellular systems, CDMA capacity issues have scarcely been addressed for HAP systems [3], [4], [5]. The other-cell interference factor and the capacity of the reverse link have been evaluated in [3] for a cellular HAP CDMA system, while the downlink performance of such a system has been examined in [4]. Both up and downlink capacity issues have also been investigated in [5] for a HAP rural macrocell integrated within a terrestrial UMTS network. However, the results of the aforementioned studies are limited by the following assumptions: 1) the number of users per cell is fixed; 2) uplink performance is evaluated under the assumption of perfect power control; and 3) an oversimplified channel model is used for the estimation of the downlink capacity.

This letter addresses only uplink capacity estimation (due to space limitations) for a WCDMA HAP station under the assumption of both power control imperfections and multiuser detection. Since network capacity is a key competence for network operators, engineers that grapple with this issue capitalize upon power control and MUD techniques. Power control improves the uplink performance both by equalizing the powers of all users in a cell (therefore, the near-far effect is alleviated) and by compensating for the channel fading. However, in real systems power control imperfections degrade the system capacity. In this letter we carry out a complete uplink capacity evaluation considering imperfect power control, letting the number of users in each cell be Poisson distributed. Moreover, MUD provides means of reducing multiple access interference, and hence increases the system capacity. We also examine the impact of the efficiency of base station MUD that cancels part of the intracell interference on both the uplink capacity and the average user transmission power.

The remainder of the letter is organized as follows. In Section II, we describe the system model as well as the user statistics. Section III presents the interference analysis that accounts for both imperfect power control and MUD. In Section IV, simulation results are presented and discussed. Finally, conclusions remarks are drawn in Section V.

II. SYSTEM MODEL AND USER STATISTICS

We assume a HAP located in the stratosphere at an altitude of 20 km, using a multibeam phased array antenna. The antenna pattern that we consider conforms to the ITU recommendations [2] and is given by

$$G(\vartheta) = \begin{cases} 34.8 - 3(\frac{\vartheta}{1.57})^2, & \text{for } 0^o \leq \vartheta \leq 4.53^o \\ 9.8, & \text{for } 4.53^o < \vartheta \leq 5.87^o \\ 55.95 - 60\log(\vartheta), & \text{for } 5.87^o < \vartheta \leq 37^o \\ -38.2, & \text{for } 37^o < \vartheta \leq 90^o \end{cases} \quad (1)$$

where $G(\vartheta)$ is the gain (in dBi) at the angle ϑ from the main beam direction. A hexagonal cellular layout is assumed and the gain of the transmitting antenna at the edge of each cell is 10 dB below the maximum gain. A reference cell is considered directly below the HAP, surrounded by N_c tiers of interfering cells. The drift due to wind or pressure variations and the movement of the HAP itself are considered to be compensated either by means of beam control or by means of an antenna steering mechanism. A specific feature of a HAP system is that all base stations are located on the HAP within a distance

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of few meters, which corresponds to the aperture of the phased array antenna. Thus, since the user signal traverses the same path towards all base stations and experiences approximately the same shadowing, a user is connected to the base station that illuminates the cell where the user is located.

We also assume that users are positioned inside each cell according to a uniform distribution. Additionally, the number of users n in each cell is Poisson distributed

$$p_n(n) = e^{-\lambda}\frac{\lambda^n}{n!} \tag{2}$$

where λ is the average number of users per cell. In [6] it is pointed out that according to this model, the number of users in a cell is statistically independent from the number of users in any other cell. This model is more realistic than the one that considers a fixed number of users per cell, since it accounts for instantaneous unequal cell loading while the average load is the same in each cell.

III. INTERFERENCE ANALYSIS

The quality of the uplink may be represented in terms of the energy per bit to noise power spectral density ratio E_b/N_0

$$\frac{E_b}{N_0} = \frac{W}{R_b}\frac{P_c e^{\alpha\theta_k}}{(1-\beta)I_{intra} + I_{inter} + n_{th}} \tag{3}$$

Power control imperfections after despreading are considered to be log-normally distributed, since log-normal imperfect power control is reckoned to be a valid assumption [7]. Then, the power received by a base station can be expressed as $P_c e^{\alpha\theta_k}$, where P_c is the nominal received power with ideal power control, α is equal to $\ln(10)/10$ and θ_k is a zero-mean gaussian random variable with standard deviation σ_p, which accounts for the variations of the received power in dB. W is the transmission bandwidth, R_b is the information bit rate, I_{intra} is the intracell interference, I_{inter} is the intercell interference, β denotes the efficiency of the MUD technique which is the percentage of I_{intra} that can be canceled with base station MUD and n_{th} is the thermal noise power. The link is considered to be in outage when E_b/N_0 is smaller than the minimum required $(E_b/N_0)_{min}$. We should also note that all interfering signals are affected with power control impairments with the same statistics as the desired signal.

A. Intracell Interference

Interference originated from users within the reference cell is given by

$$I_{intra} = \sum_{i=1}^{M_0-1} P_c e^{\alpha\theta_{k_i}} \tag{4}$$

where M_0 is the number of users in the reference cell.

B. Intercell Interference

The signal power $P_{R_{ji}}$received by the j^{th} base station BS_j from the i^{th} user within its cell coverage may be expressed (in dB) as

$$P_{R_{ji}} = P_{T_i} - L_{ji} + G_{R_{ji}} + G_{T_{ji}} \tag{5}$$

where P_{T_i} is the user's transmission power, L_{ji} denotes the losses due to free space attenuation and shadowing, while $G_{R_{ji}}$ and $G_{T_{ji}}$ are the gains of the receiving and the transmitting antennas respectively, evaluated at the angle under which the i^{th} user is seen from BS_j. The interference power $P_{R_{0i}}$ from this user to the base station BS_0 that illuminates the reference cell is

$$P_{R_{0i}} = P_{T_i} - L_{0i} + G_{R_{0i}} + G_{T_{0i}} \tag{6}$$

where L_{0i} indicates the losses due to free space attenuation and shadowing, while $G_{R_{0i}}$ and $G_{T_{0i}}$ are the gains of the receiving and the transmitting antennas respectively, evaluated at the angle under which the i^{th} user is seen from BS_0. However, the signal traverses the same path to both base stations, therefore, $L_{ji} = L_{0i}$ and $G_{T_{ji}} = G_{T_{0i}}$. By replacing $G_{T_{0i}}$ in (6) with (5) and considering that the power received by BS_j after despreading is $P_c e^{\alpha\theta_k}$,we have

$$I_{inter} = \sum_{j=1}^{K}\sum_{i=1}^{M_j}\frac{G_{R_{0i}}}{G_{R_{ji}}}P_c e^{\alpha\theta_{k_{ji}}} \tag{7}$$

where K is the number of surrounding cells and M_j is the number of users in the j^{th} cell.

C. Power Saving

Except for cancelling part of I_{intra}, base station MUD can also be employed to decrease the average transmission power of a user. The employment of MUD results in an increase in the average E_b/N_0, which in turn corresponds to a decrease in outage probability. Consequently, the difference between $(E_b/N_0)_{MUD}$ of a system with MUD and (E_b/N_0) of a system without MUD accounts for the potential reduction in the received power of the user under consideration. As it can be seen in (5), P_{T_i} is determined only by $P_{R_{ji}}$ since all the other terms remain the same. Thus, the decrease in the required transmission power P_S (in dB) with MUD is

$$P_S = (E_b/N_0)_{MUD} - (E_b/N_0) \tag{8}$$

IV. SIMULATION RESULTS

To evaluate the uplink capacity, Monte Carlo simulations were carried out and the number of iterations was 2^{20} (different initial seeds were used in every iteration for the generation of both the users' positions and the number of users in each cell). Before conducting the main set of simulations, we had to evaluate the number of tiers N_C that we were going to simulate. Several simulations runs showed that I_{inter} stems mainly from the first three tiers, and hence, we set $N_C = 3$ for the rest of the simulations. We also set $W = 5$ MHz, $P_c/n_{th} = -1$ dB, while we evaluated the system uplink capacity for three different service classes, which are presented in Table I.

TABLE I

QOS PARAMETERS FOR 3G MULTIMEDIA SERVICES

R_b $[kbps]$	$(E_b/N_0)_{min}$ [dB]	Typical Applications
12.2	5	Voice
144	1.5	Real-time data
384	1	Non-real-time data

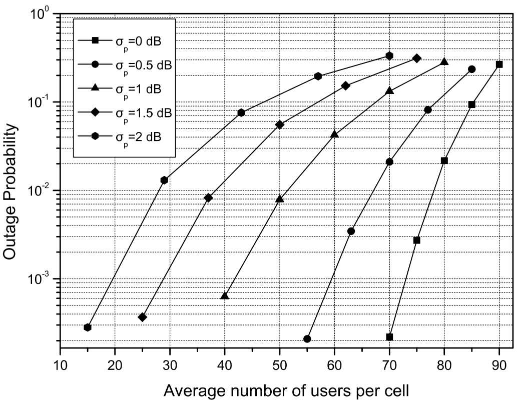

Fig. 1. Outage probability as a function of the average number of users per cell for different values of σ_p and $R_b = 12.2\ kb/s$.

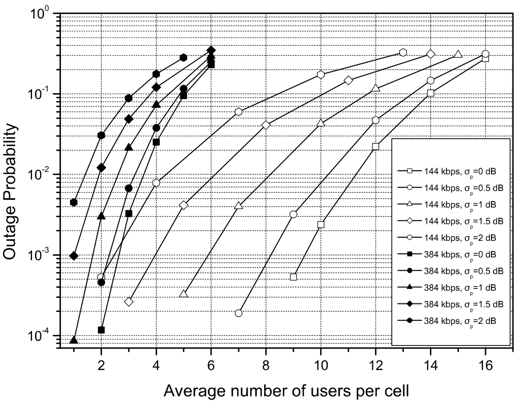

Fig. 2. Outage probability as a function of the average number of users per cell for different values of σ_p and $R_b = 144$ and $384\ kb/s$.

First, we assess the effect of imperfect power control standard deviation σ_p on the uplink capacity in terms of outage probability P_o. In Fig. 1, P_o for different values of σ_p and $R_b = 12.2\ kbps$ is depicted as a function of the average number of users per cell. At $P_o = 10^{-2}$, every 0.5 dB error translates into a capacity loss of at least 10 users per cell.

Fig. 2 illustrates the impact of power control impairments on outage probability for $R_b = 144$ and $384\ kbps$. At $P_o = 10^{-2}$, every 1 dB error results in a capacity loss of 4 users per cell for $R_b = 144\ kbps$ and 1 user per cell for $R_b = 384\ kbps$. This fact motivates the use of base station MUD.

The effect of MUD efficiency β on system capacity is shown in Fig. 3 for $\sigma_p = 1$ dB. Obviously, MUD ameliorates the detrimental effects of power control imperfections. MUD with $\beta = 0.2$ compensates for the decrease in system capacity owing to imperfect power control.

Apart from increasing the uplink capacity, base station MUD may result in a decrease in the transmission power of a user transmitting at full power. In Fig. 4 the decrease in the average transmission power of a user is shown as a function of β and R_b, assuming that the propagation loss is lower than the maximum loss allowed for a system without MUD. Taking into account that usually there exist quite a few users whose transmission power can be reduced, a further decrease in the average transmission power may be accomplished.

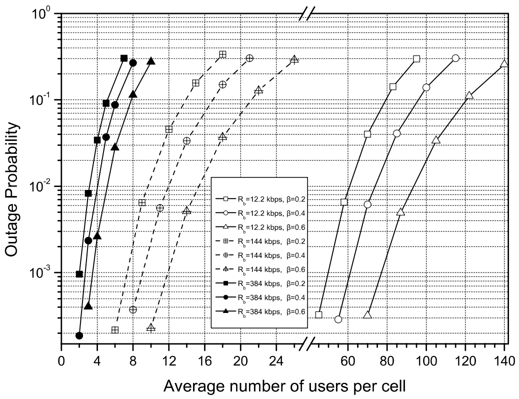

Fig. 3. Outage probability as a function of the average number of users per cell for different values of MUD efficiency β and R_b ($\sigma_p = 1$ dB).

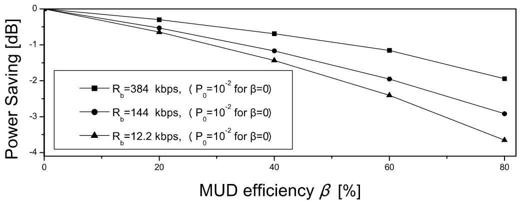

Fig. 4. Saving in average user transmission power as a function of the MUD efficiency β for different values of R_b ($\sigma_p = 1$ dB).

V. CONCLUSIONS

In this letter, we evaluated the impact of power control imperfections on the uplink capacity of a WCDMA HAP system. Our study is predicated upon a model according to which the number of users in each cell is Poisson distributed rather than fixed. It was shown that imperfect power control significantly decreases the system capacity. Moreover, MUD was proved to be a stepping stone to both the increment in system capacity and the decrease in average user transmission power.

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