Quasi-optimum Downlink Power Control Scheme of High Altitude Platform W-CDMA System

Bazil Taha Ahmed, Miguel Calvo Ramón, and Leandro de Haro Ariet

Abstract—The performance of a quasi-optimum distance based downlink power control model is evaluated for high altitude platform station (HAPS) W-CDMA systems using 19 cells model. We have generalized a previous model proposed by Gejji. The downlink capacity using our model is higher than the capacity evaluated using the old model.

Index Terms—Downlink capacity, HAPS, power control, W-CDMA, Gejji model.

I. INTRODUCTION

WIRELESS communications using high altitude platform stations (HAPS) have been proposed worldwide due to the many advantages of HAPS systems over terrestrial tower-based and satellite systems [1]. Recently, it has been accepted to use HAPS as an alternative to deliver the third generation IMT-2000 wireless services.

Downlink power control is used in cellular W-CDMA systems to equalize the CIR amongst users in each cell. The performance of a distance based power control scheme, based on an n-th exponent of mobile's normalized distance from the centre of its serving cell, has been analyzed in [2] and has been used to evaluate the downlink capacity of W-CDMA HAPS system in [3].

In this work, we use a (n - th) power of normalized distance power control scheme to calculate the power reduction factor due to the use of the power control strategy and to calculate the HAPS downlink capacity of the W-CDMA system using the same methodology given in [3].

II. HAPS SYSTEM MODEL

A HAPS carrying a W-CDMA communication payload and a multi-beam phased array antenna, with beam/gain shaping capability, and positioned at an altitude (h) of 22 km was proposed in [3]. The antenna radiation pattern and the HAPS downlink interference geometry are shown in Figs. 1 and 2, respectively.

A user in the HAPS service area will experience intracellular interference from its serving beam (cell) and intercellular interference from the adjacent beams (cells). Let (r,θ) be the coordinates of the mobile under consideration with respect to the centre of the cell projected

Manuscript received October 01, 2002; revised April 2, 2003.

The authors are with the Departamento Sistemas, Señales y Radiocomunicaciones, ETSI Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria, Madrid, 28040. (e-mail: bazil@gr.ssr.upm.es).

Publisher Item Identifier S 1682-0053(03)0178





Fig. 2. HAPS downlink interference geometry.

by its serving beam. Using downlink power control strategy, the power transmitted to a mobile located at distance r is given by:

$$P_t(r) = P_R f(r) \tag{1}$$

where P_R is the reference power level assigned to the user located at the cell limit r = R and f(r) is the power profile.

For the old power control model (Gejji Model), the power profile $f_{old}(r)$ is given as

$$f_{old}(r) = \begin{cases} \left(\frac{r_o}{R}\right)^n & \text{for} \quad r \le r_o \\ \left(\frac{r}{R}\right)^n & \text{for} \quad r > r_o \end{cases}$$
(2)

Here $P_t(r)$ is assumed to be proportional to the normalized distance raised to n, but every user located at a distance less than r_o is assured by a minimum amount of transmitted power. The drawback of this model is that the power assigned to users near to the cell centre is more than the real need, especially when the orthogonality between the users is maintained using the (HAP) system. To solve this drawback we propose a new model in which the power assigned to users near the centre of the cell is reduced according to the system situation.

Assuming a uniform distribution of N users within the cell, the user's density ρ is:

$$\rho = \frac{N}{\pi R^2} \,. \tag{3}$$

The total power (P_T) transmitted to the users by the base station is given by:

$$P_{T} = \frac{N P_{R}}{\pi R^{2}} \int_{0}^{R^{2}\pi} \int_{0}^{d\theta} f(r) r \, dr = \frac{2N\pi P_{R}}{\pi R^{2}} \int_{0}^{R} f(r) r \, dr$$
(4)
= 2Nf_{p}P_{R} = N\kappa P_{R}

for the old model

$$\kappa_{old} = \frac{2}{n+2} + \frac{n}{n+2} \left(\frac{r_o}{R}\right)^{n+2}.$$
(5)

The power profile of the new proposed model is given by

$$f_{new}(r) = \sum_{m=0}^{M} a_m \left(\frac{r}{R}\right)^m.$$
(6)

The total transmitted power factor (P_{Tnew}) is given as

$$P_{Tnew} = NP_R \kappa_{new} \tag{7}$$

where

$$\kappa_{new} = \sum_{m=0}^{M} \frac{a_m}{m+2} \,. \tag{8}$$

The factors $a_0, a_1, ..., a_M$ are found from the curve fitting of the normalized interference profile given by (12). In our analysis we use M = 6.

III. DOWNLINK CAPACITY ANALYSIS

A model of 19 cells with a radius of 1 km is used in the analysis. The outer cells are slightly noncircular. Since the height of the HAP is greater than the radius of the service area then the effect of the elliptic shape of the outer cells can be neglected (the shape distortion is less than 2.5%). In our study, the effect of the receiver noise is neglected.

Let BS_j (0,1,...,J) denotes the base station serving the *j*-th cell (beam) as shown in Fig. 2. For a mobile located at (r, θ) in the reference cell served by BS_0 , the carrier-tointerference ratio (C/I) is defined by:

$$\frac{C}{I} \approx \frac{P_{ch}P_{t}(r)G(\psi_{0})l_{0}^{-\alpha}\xi_{0}/\beta}{P_{T}G(\psi_{0})l_{0}^{-\alpha}\xi_{0}(1-\phi) + \sum_{j=1}^{J}P_{T}G(\psi_{j})l_{j}^{-\alpha}\xi_{j}}$$
(9)

where

- P_{ch} is the power assignment for the user's channels ≈ 0.8 ,
- *l_j* and *l₀* are the distances from the mobile to *BS_j* and *BS₀* respectively,
- ξ_j and ξ_0 denote the shadowing effect corresponding to these two paths,
- α is the path propagation loss exponent = 2,
- $G(\psi_j)$ and $G(\psi_0)$ are the normalized antenna gains evaluated at the angles under which the mobile is seen from the antenna boresights of BS_j and BS_0 respectively,
- β is the source activity factor and
- ϕ is the orthogonality factor (≥ 0.5) for the HAP system.

Due to the unique HAPS geometry, the transmit antenna beams for all base stations essentially originate from the same point [3], so $l_j \approx l_0$ and $\xi_j \approx \xi_0$ (highly correlated shadowing).

Now the ratio (C/I) for a user at a distance r and an angle θ can be given as:

$$\frac{C}{I} \approx \frac{P_{ch} P_l(r) / \beta}{P_T \gamma(r, \theta)}$$
(10)

where

$$\psi(r,\theta) = \frac{(1-\phi)G(\psi_0) + \sum_{j=1}^{o} G(\psi_j)}{G(\psi_0)}.$$
 (11)

The normalized $\gamma_n(r,\theta)$ is given by

$$\gamma_n(r,\theta) = \frac{\gamma(r,\theta)}{\gamma(R,\theta)}.$$
(12)

Substituting for P_T we get

$$\frac{C}{I} \approx \frac{P_{ch}P_t(r)/\beta}{(2N(r)P_Rf_p)\gamma(r,\theta)} = \frac{P_{ch}P_Rf(r)/\beta}{(2N(r)P_Rf_p)\gamma(r,\theta)} = \frac{P_{ch}f(r)/\beta}{(2N(r)P_Rf_p)\gamma(r,\theta)}$$
(13)

where N(r) is defined as the downlink users profile. Now the ratio E_b / N_o is given by

$$\frac{E_b}{N_o} = \left(\frac{C}{I}\right) G_p \approx \frac{G_p P_{ch} f(r) / \beta}{(2N(r) f_p) \gamma(r, \theta)}$$
(14)

where G_p is the W-CDMA processing gain.

The downlink users profile N(r) at distance r is obtained from (14) as

$$N(r) \approx \frac{G_p P_{ch} f(r) / \beta}{\left(\frac{E_b}{N_o}\right)_{req} (2f_p) \gamma(r, \theta)}.$$
(15)

The downlink capacity (C_{down}) is given by the minimum value of N(r) as:

$$C_{down} = \min[N(r)]. \tag{16}$$



Fig. 3. HAPS downlink capacity profile against normalized distance from cell center, $\phi = 0$ for voice users.

The power control reduction factor $\kappa = 2f_p$ is given by:

$$\kappa = 2f_p = \frac{P_{Tc}}{P_{Tnc}} \tag{17}$$

where

- P_{T_c} is the base station total transmitted power for the users with power control and
- P_{Tnc} is the base station total transmitted power for the users without power control.

It is noteworthy that the more flat is the users profile N(r)the better is the power control scheme.

IV. NUMERICAL RESULTS

For the HAP system, we assume the following,

- $h = 22.5 \,\mathrm{km}$ and
- R = 1 km and a continuous power control.
- We assume the following values, typical of a voice service $G_p = 256$, $(E_b / N_o)_{req} = 6 \text{ dB}$, and $\beta = 0.5$.

Using the formulation provided in [3] the best results are obtained when $(n = 2.7 \text{ and } r_o / R = 0.71)$. First, we compare the downlink capacity using the old and the proposed new model. Fig. 3 shows the capacity profile N(r) using the old and the new models for $\theta = 30$ deg., $r_o/R = 0.71$ and $\phi = 0$ (no orthogonality). The downlink capacity (the minimum value of N(r) of each curve in the figure) are 60 users and 70 users for the old and the new models, respectively. Thus, the capacity increment using the new model is 16.6 %. The required dynamic range of the power control is 4 dB and 5 dB for the old and new model respectively. The power reduction factor κ_{new} of our model has a value of 0.4590 while the value of κ_{old} of the old model is 0.5404.

Next, we study the case of some orthogonality ($\phi \neq 0$). Fig. 4 shows the capacity profile N(r) when the orthogonality factor $\phi = 0.5$ (practical case). For the new model, the downlink capacity is 107 users (minimum value of N(r)) in the figure while the value provided by the old formulation is 71 users since the old model does not take into account the orthogonality factor (drawback of the old model). The power reduction factor κ_{new} of our model has



Fig. 4. HAPS downlink capacity profile against normalized distance from cell center, $\phi = 0.5$ for voice users.



Fig. 5. HAPS downlink capacity profile against normalized distance from cell center using the new model, $\phi = 0.5$ for data users.

a value of 0.3569 while the value of κ_{old} of the old model is 0.5404. For the new model, the capacity profile N(r) is quasi-straight line and thus the power control scheme is quasi-optimum. Using the new model, the required dynamic range of the power control in this case is 6.9 dB.

Then we assume the following values, typical of a data service (144 kbit/sec)

- $G_p = 26.6$, $(E_b / N_o)_{req} = 3$ dB, and

Fig. 5 shows the capacity profile when $\phi = 0.5$. We can notice that the downlink capacity is 11 data users.

It is noteworthy that the capacity profile reflects the value of the CIR of the users in the point r and it is given for uniformly distributed users within the cell [3], [4].

Results for $\theta = 0 \deg$ can be get in the same way in which we get the results for $\theta = 30 \text{ deg.}$

V.CONCLUSIONS

In this study, the performance of a quasi-optimum distance based downlink power control model is evaluated for high altitude platform station (HAPS) W-CDMA systems. For the non-orthogonality case (the only case of the old model), the downlink capacity using the new model is 16.6% higher than the capacity evaluated using the old model proposed by Gejji. In the case of some orthogonality, the capacity difference becomes even higher (50.7%). Moreover our model is more general than the old model, i.e. it can be used for all values of the orthogonality factor ϕ .

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Bazil Taha Ahmed was born in Mosul, Iraq, in 1960. He received the B.Sc. and M.Sc. degrees in communication engineering from the University of Mosul, in 1982 and 1985, respectively.

From 1985 to 1998, he was teaching at the Electrical Engineering Department at Mosul University.

Now he is doing his Ph.D. study at the Technical University of Madrid. His research interests include W-CDMA capacity and electromagnetic wave propagation in micro-cellular and macro-cellular environments.

Miguel Calvo Ramón was born in Pueyo de Jaca, Huesca, Spain in 1949. He received the M.Sc. and Ph.D. both in telecommunications from the Universidad Politécnica de Madrid in 1974 and 1979, respectively. He is presently a Professor in the Signals, Systems and Radiocommunications Department in the same university since 1986.

Since his incorporation to the University in 1974 he has worked in a number of projects in the areas of numerical methods in electromagnetics, electromagnetic compatibility, communication systems and satellite communications.

Since 1998 he has participated as a delegate in the ITU-R TG8.1 meetings that developed the IMT-2000 standards and in the follow up ITU-R WP8F for upgrades and systems beyond IMT-2000.

He was a Research Visitor at Queen Mary College, London University in 1983 and Technical Visitor at Nichols Center, Kansas University in Lawrence in 1993. he has co-authored a number of papers in technical reviews and contributed in a number of international conferences. He wrote a chapter in the book "Reflector and Lens Antennas. Analysis and Design using Personal Computers", C. J. Sletten editor, Artech House 1988, contributed two chapters in "Modelling and Simulation environment for Satellite and Terrestrial Communication Networks," Kluwer Academic Publishers 2002, and edited "Sistemas de Comunicaciones Móviles de Tercera Generación IMT-2000 (UMTS)," Fundación Airtel-Vodafone 2002.

Leandro de Haro Ariet was born in Barcelona, Spain, in 1962. He received the M.Sc. and Ph.D. both in telecommunication from the Universidad Politécnica de Madrid in 1986 and 1992, respectively.

Since 1990 he develops his professional career in the Signals, Systems and Radiocommunications Department of the Universidad Politécnica de Madrid as an Assistant Professor.

His research interests include antenna design for satellite communications, satellite communication systems and Study and design of digital TV communication systems. He has been actively involved in several research projects in cooperation with public and private companies. He has also been involved in several European projects.