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

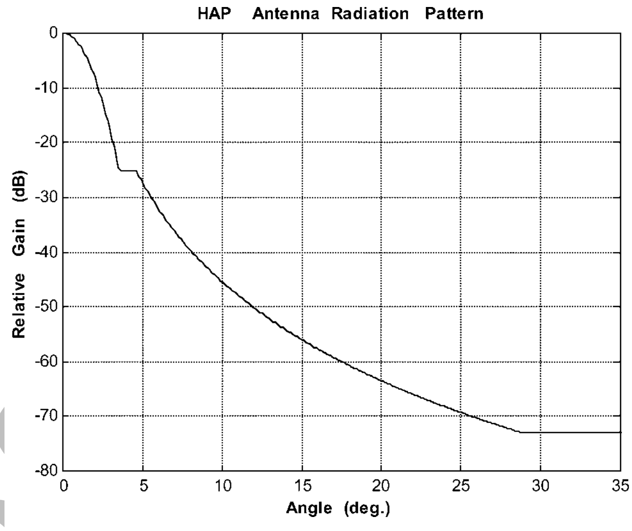

Fig. 1. The antenna radiation pattern envelope.

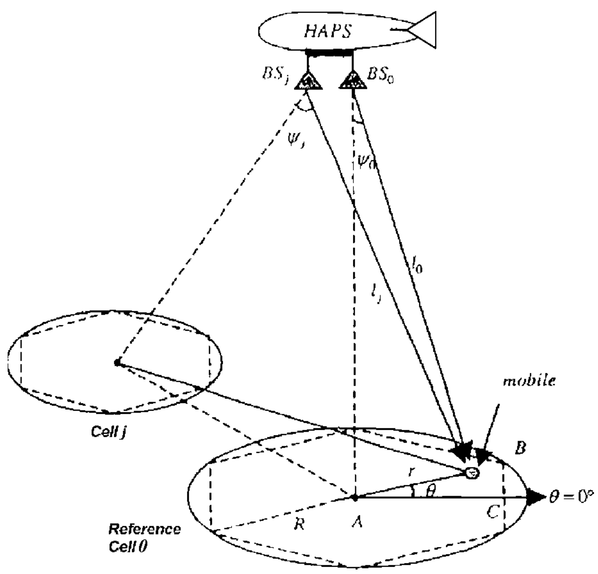

Fig. 2. HAPS downlink interference geometry.

$$P_t(r) = P_R f(r) \quad (1)$$

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

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

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:

$$P_T=\frac{N P_R}{\pi R^2}\int_0^R\int_0^{2\pi} d\theta\ f(r) r\, dr=\frac{2N\pi P_R}{\pi R^2}\int_0^R f(r)\, r\, dr = 2Nf_pP_R=N\kappa P_R \tag{4}$$

for the old model

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

The power profile of the new proposed model is given by

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

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-to-interference ratio (C/I) is defined by:

$$\frac{C}{I}\approx\frac{P_{ch}P_t(r)G(\psi_0)l_0^{-\alpha}\xi_0/\beta}{P_TG(\psi_0)l_0^{-\alpha}\xi_0(1-\phi)+\sum_{j=1}^{J}P_TG(\psi_j)l_j^{-\alpha}\xi_j} \tag{9}$$

where

- P_{ch} is the power assignment for the user's channels ≈ 0.8,
- l_j and l_0 are the distances from the mobile to BS_j and BS_0 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:

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

where

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

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

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

Substituting for P_T we get

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

where $N(r)$ is defined as the downlink users profile.

Now the ratio E_b/N_o is given by

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

where G_p is the W-CDMA processing gain.

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

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

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

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

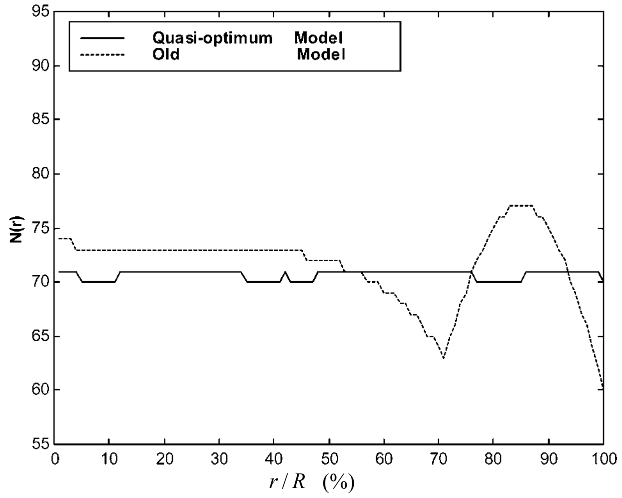

Fig. 3. HAPS downlink capacity profile against normalized distance from cell center, $\phi = 0$ for voice users.

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

$$\kappa = 2 f_p = \frac{P_{Tc}}{P_{Tnc}} \qquad (17)$$

where

- P_{Tc} 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,

- $h = 22.5$ km and
- $R = 1$ km and a continuous power control.

We assume the following values, typical of a voice service

- $G_p = 256$,
- $(E_b / N_o)_{req} = 6$ dB, and
- $\beta = 0.5$.

Using the formulation provided in [3] the best results are obtained when ($n = 2.7$ 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

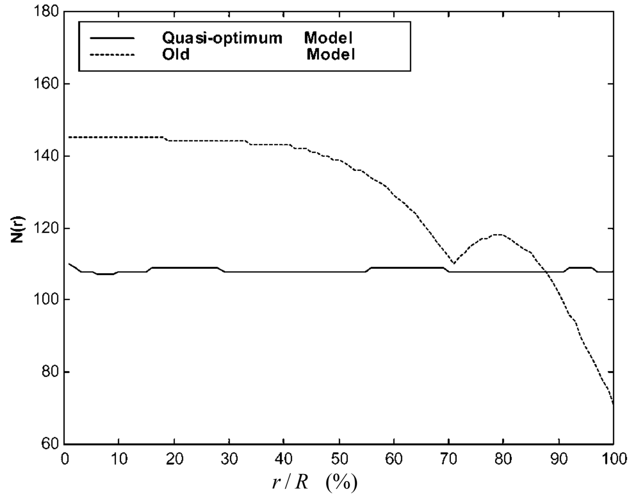

Fig. 4. HAPS downlink capacity profile against normalized distance from cell center, $\phi = 0.5$ for voice users.

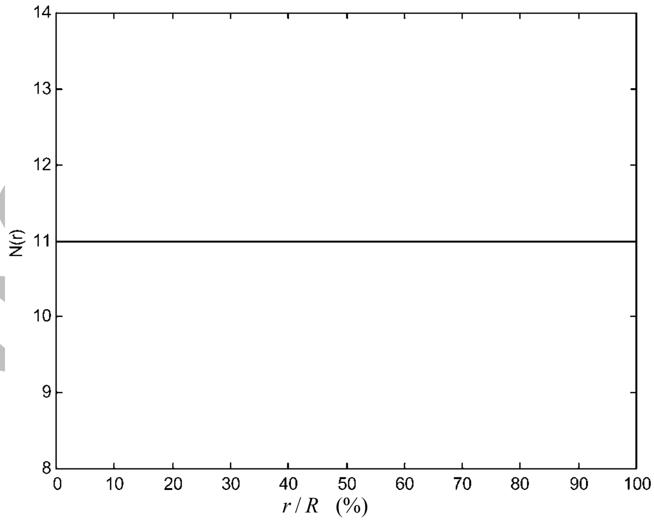

Fig. 5. HAPS downlink capacity profile against normalized distance from cell center using the new model, $\phi = 0.5$ for data users.

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
- $\beta = 1$.

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 $\theta = 30$ 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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