On the High Altitude Platform (HAP) W-CDMA System Capacity

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Abstract. *The performance of a downlink power control model, based on a n-th power distance law, is evaluated for high altitude platform station (HAPS) W-CDMA systems. The downlink capacity using this model is compared with the uplink capacity. It is shown that the uplink capacity is higher than the downlink capacity.*

Keywords

Downlink capacity, uplink capacity, HAPS, power control, WCDMA.

1. Introduction

There is an insatiable demand for communications services throughout the world, driven largely by the need for Internet access. Wireless offers the only viable provision means in many scenarios, but both terrestrial and satellite systems suffer from fundamental limitations in cost and capacity. One potential delivery method is from High Altitude Platforms (HAPs), which are pilotless solar-powered airships or aircraft operating at an altitude of up to 25 km. A HAP may be viewed as either a very tall radio mast or a very low stationary satellite, and can offer communications services with the best features of both.

Airship technology is developing steadily, with commercial applications becoming more of a reality. Wireless communication from HAPs offers considerable potential for new broadband services, for mobile phones and for niche markets such as disaster relief or military where rapid deployment is a key feature.

Wireless communications using HAPS have been proposed world wide due to the many advantage of HAPS system over terrestrial tower-based and satellite systems [1]. Recently it has been accepted to use HAPS as an alternative means to deliver the third generation IMT-2000 wireless services.

Forward link power control is used in cellular W-CDMA systems to reduce the interference to the other neighboring cells and increase system capacity. The performance of a distance based power control scheme based on an n-th exponent of mobile's distance from the center of its serving cell was studied in [2] and used to analyze the forward link capacity of high altitude platform W-CDMA system in [3] (for voice service only). The drawback of the above mentioned n-th power of distance power control scheme is that it is suitable only for environments with low orthogonality factor between the users ($\phi \approx 0.0$) that is not the real case for the HAPs W-CDMA system in which ϕ ranges from 0.4 to 0.6 in practice. For that reason we propose here an improved form of the above mentioned power control scheme.

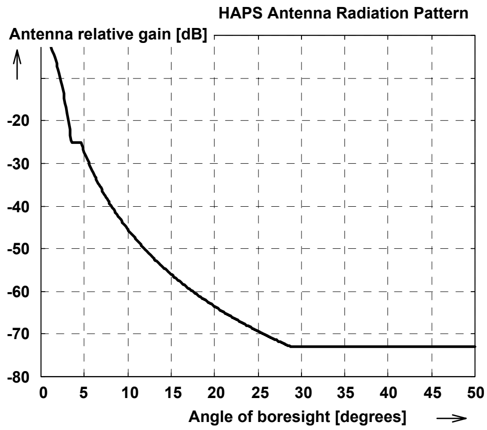

Fig. 1. The antenna radiation pattern.

In this work, we use the improved n-th power of distance power control scheme to calculate the HAPS downlink capacity of a W-CDMA using the methodology given in [3] and then we compare it with the uplink capacity.

2. HAPs Downlink Power Control Model

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

A user in the HAPS service area will experience intracellular interference from its serving beam users and intercellular interference from the adjacent beams users. Let (r, q) be the coordinates of the mobile with respect to the center of the cell projected by its serving beam.

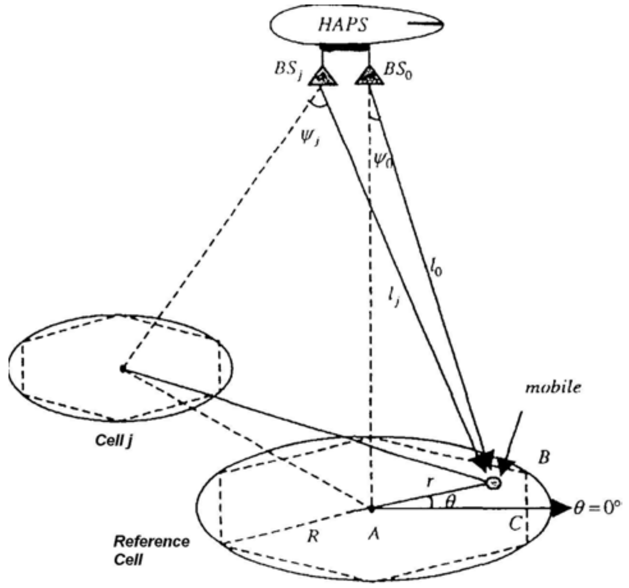

Fig. 2. HAPS down link interference geometry.

Using downlink power control, 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 $r = R$.

The new power profile $f_{new}(\ r)$ is given as [4]:

$$f_{new}(r) = \begin{cases} \left[a + b\left(\dfrac{r}{r_0}\right)^{n_1} \right] \left[\dfrac{r_0}{R}\right]^n & \text{for } r \le r_0 \\ \left[\dfrac{r}{R}\right]^n & \text{for } r > r_0\ , \end{cases} \tag{2}$$

where $n_1 > 1$, a and b are the power control scheme parameters such that $a + b = 1$, and r_0 is the distance at which the power control scheme changes the law of the power control.

The users density ρ, assuming a uniform distribution of N users in the cell, is

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

The total power transmitted by the base station is

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

$$= \frac{2 N \pi P_R}{\pi R^2} \int_0^R f(r) r\, dr = 2 N \pi P_R\, f_P\ , \tag{5}$$

where

$$2 f_{p,new} = a\left[\frac{r_0}{R}\right]^{n+2} + \frac{2b}{n_1 + 2}\left[\frac{r_0}{R}\right]^{n+2} + \\ + \frac{2}{n+2} - \frac{2}{n+2}\left[\frac{r_0}{R}\right]^{n+2}\ . \tag{6}$$

3. Downlink Capacity

Let BS_j(j = 0, …, J) denote the base station serving the j-th cell, as shown in Fig. 2. For a mobile located at (r, q) in the reference cell served by BS_0, the carrier-to-interference ratio (C/I) is given by

$$\frac{C}{I} \approx \frac{P_{ch} P_t(r) G(\psi_0) l_0^{-\alpha} \zeta_0 / \beta}{P_T\, G(\psi_0) l_0^{-\alpha} \zeta_0 (1-\phi) + \sum_{j=1}^{J} P_T\, G(\psi_j) l_j^{-\alpha} \zeta_j}\ , \tag{7}$$

where P_{ch} is the power assignment for the users channels cca 0.8, l_j and l_0 are the distances from the mobile to BS_j and BS_0 respectively, ζ_j and ζ_0 denote the shadowing corresponding to these two paths, α is the path loss exponent equal 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 voice activity factor = 0.5, ϕ is the orthogonality factor.

Due to the unique HAPS geometry, the transmit antenna beams of all base stations essentially originate from the same point [3], so $l_j \approx l_0$ and $\zeta_j \approx \zeta_0$ (quasi total correlation).

Now the carrier to interference ratio (C/I) can be given as:

$$\frac{C}{I} = \frac{P_{ch} P_t(r) / \beta}{P_T\, \gamma(r,\theta)}\ , \tag{8}$$

where

$$\gamma(r,\theta) = \frac{(1-\phi) G(\psi_0) + \sum_{j=1}^{J} G(\psi_j)}{G(\psi_0)}\ . \tag{9}$$

Substituting for P_T we get

$$\frac{C}{I} \approx \frac{P_{ch} P_t(r) / \beta}{\left[2 N(r) P_R\, f_p\right]\ \gamma(r,\theta)}\ , \tag{10}$$

$$\frac{C}{I} \approx \frac{P_{ch} P_R\, f(r) / \beta}{\left[2 N(r) P_R\, f_p\right]\ \gamma(r,\theta)}\ , \tag{11}$$

$$\frac{C}{I} \approx \frac{P_{ch}\, f(r) / \beta}{\left[2 N(r) P_R\, f_p\right]\ \gamma(r,\theta)}\ , \tag{12}$$

where $N(\ r)$ is the downlink user capacity profile.

Now the ratio (E_b/N_0) is given by

$$\frac{E_b}{N_0} = \left[\frac{C}{I}\right] G_p \ , \qquad (13)$$

where G_p is the W-CDMA processing gain. From (12),

$$\frac{E_b}{N_0} \approx \frac{G_p\, P_{ch}\, f(r)/\beta}{\left[2\,N(r) P_R\, f_p\right]\ \gamma(r,\theta)} \ . \qquad (14)$$

From this equation, the downlink capacity profile $N(\ r)$ at the distance r is given as:

$$N(r) \approx \frac{G_p\, P_{ch}\, f(r)/\beta}{\left[E_b/N_0\right]_{req}\ \left[2\, f_p\right]\ \gamma(r,\theta)} \ . \qquad (15)$$

The downlink capacity (C_{down}) is given by:

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

A computer program has been used to evaluate the optimum values of a, b, n_1, n and r_0.

4. HAP Uplink Capacity

In this section we will study the uplink capacity as a function of the cell radius.

4.1 Intracellular Interference

Assuming that the power level of the desired signal is S, the intracellular interference I_{intra} is given by:

$$I_{intra} = \alpha\left(N_u - 1\right) S \ . \qquad (17)$$

4.2 Intercellular Interference

We will assume that (i, j) denotes the i-th mobile at the j-th cell and that the beam B_j is the beam that serves the mobile (i, j). The mobile (i, j) is at a distance $r_{i,j}$ from the center of the cell under study. The transmitted power of the mobile (i, j) is given by:

$$S_{T,j} = S l_j^5\ 10^{-\zeta_j/10}\ 10^{-G(\psi_j)/10} \ . \qquad (18)$$

The interference produced by the mobile (i, j) is given by:

$$I_{B_0} = S\left[\frac{l_j}{l_{0,j}}\right]^5\ 10^{\frac{\zeta_{0,j}-\zeta_j}{10}}\ 10^{\frac{G(\psi_{0,j})-G(\psi_j)}{10}} \ , \qquad (19)$$

$$I_{B_0} \approx S\ 10^{\frac{G(\psi_{0,j})-G(\psi_j)}{10}} \ . \qquad (20)$$

The intercellular interference I_{inter} due to the J cells near the cell under consideration is given by:

$$I_{inter} = \alpha\, S\, N_u \sum_{j=1}^{J} \int_A 10^{\frac{G(\psi_{0,j})-G(\psi_j)}{10}}\ dA \ , \qquad (21)$$

$$I_{inter} = \alpha\, S\, N_u \sum_{j=1}^{J} \int_0^{2\pi}\!\!\int_0^{R} 10^{\frac{G(\psi_{0,j})-G(\psi_j)}{10}}\ \frac{r_j\, dr_j\, d\theta_j}{\pi R^2} \ , \qquad (22)$$

$$I_{inter} = \alpha\, S\, N_u\ F_u \approx I_{intra}\ F_u \ . \qquad (23)$$

4.3 Uplink Total Interference

The uplink total interference I_t is given by:

$$I_t = I_{intra}\left(1 + F_u\right) \ . \qquad (24)$$

The $(C/I)_{up}$ is given by:

$$\left[C/I\right]_{up} = S/I_t \ . \qquad (25)$$

The ratio $(E_b/N_0)_{up}$ is given by:

$$\left[E_b/N_0\right]_{up} = G_p\ \left[C/I\right]_{up} \ . \qquad (26)$$

5. Numerical Results

We assume a platform altitude of h = 22.5 km, cells radius of R = 1 km and a continuous power control. We first study the case of voice only users assuming that:

- G_p = 25.6,
- $(E_b/N_0)_{req}$ = 7 dB,
- α = 0.5.

We begin with the case ϕ = 0. Fig. 3 shows $N(\ r)$ for the following obtained optimum values: n = 2.8, r_0/R = 0.75, n_1 = 6 and a = 0.72. As can be seen the capacity per beam is of 50 users.

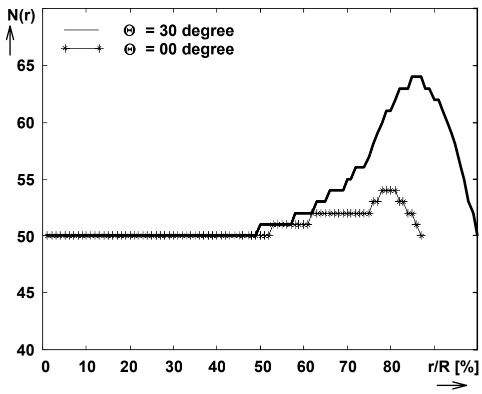

Fig. 3. HAPS down link capacity profile against normalized distance from cell centre for voice users (ϕ = 0).

Next we study the case ϕ = 0.5, which is the practical case. Fig. 4 shows $N(\ r)$ for the following obtained optimum values: n = 3, r_0/R = 0.90, n_1 = 6 and a = 0.28. The downlink capacity per beam is now 71 users.

Using the previous set of parameters n, r_0/R, n_1 and a, we study now the case of data only users assuming the following typical values:

- G_p = 26.6,

- $(E_b/N_0)_{req}$ = 3 dB,
- α = 1.

From Fig. 5, we can notice that the downlink capacity is 9 data users per beam.

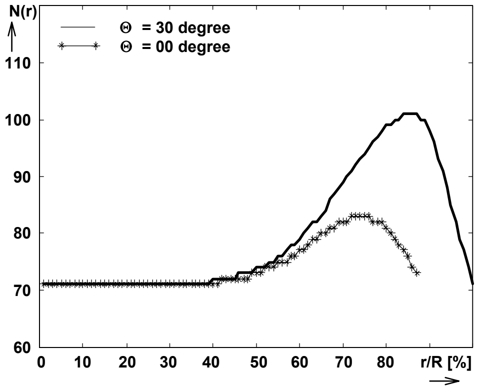

Fig. 4. HAPS down link capacity profile against normalized distance from cell center for voice users (ϕ = 0.5).

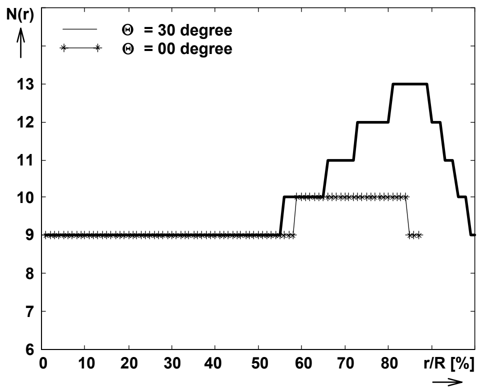

Fig. 5. HAPS down link capacity profile against normalized distance from cell centre for data users (ϕ = 0.5).

For the uplink we will assume the same values used for the downlink of G_p, $(E_b/N_0)_{req}$ and α for voice and data services.

Fig. 6 shows the F_u factor as a function of the cell radius. We can notice that the F factor reduces with the increment of the cell radius R. Calculations have been done assuming that the number J of cells that produces the intercellular interference is 18 (2 tiers).

Fig. 7 shows the uplink capacity as a function of the cell radius for voice service. It can be noticed that the capacity increases with the cell radius R. For R = 1000 m (typical cell radius for over-cities HAPs systems), the uplink capacity is 89 voice users per beam. Thus, the capacity for the uplink is higher than for the downlink.

Fig. 8 shows the uplink capacity as a function of R for data service. It can be noticed that the capacity increases with the cell radius R. For R = 1000 m, the uplink capacity is 11 data users per beam. Again, the capacity for the uplink is higher than for the downlink.

In practical systems the power control is imperfect. The practical capacity of the HAP system considered here, for an orthogonality factor of 0.5, would be of around 55 voice users, or 7 data users, per cell (beam). For a HAPS system with 19 beams the total practical capacity of the system would be in the order of 1045 voice users or 133 data users.

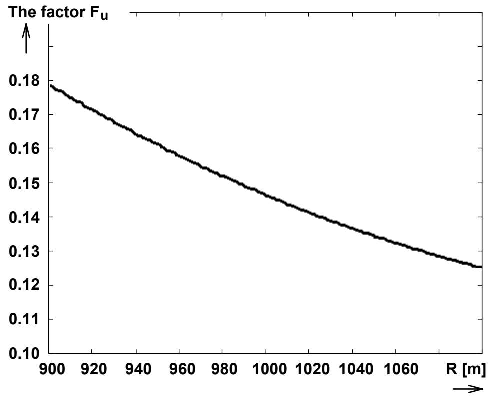

Fig. 6. The factor F_u as a function of R.

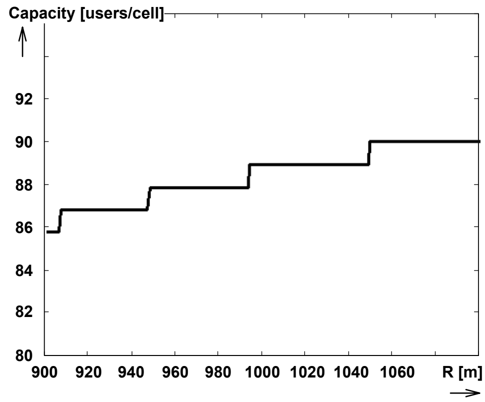

Fig. 7. The uplink capacity as a function of R (voice users).

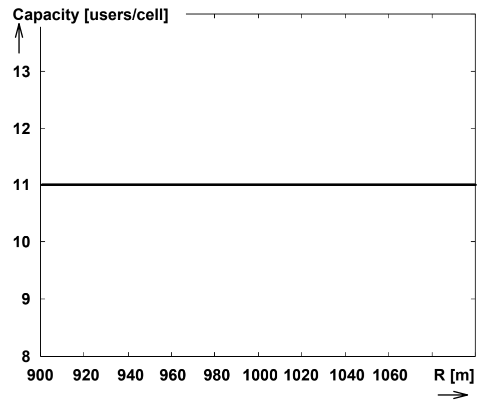

Fig. 8. The uplink capacity as a function of R (data users).

6. Conclusions

In this work, the performance of a modified n-th power distance based downlink power control model is evaluated for high altitude platform stations (HAPS) W-CDMA systems. The downlink capacity has been compared with the uplink capacity. It has been shown that the downlink capacity is lower than the uplink capacity. The downlink system capacity for an orthogonality factor of 0.5 is in the order of 71 voice users per cell or 9 data users per cell while the uplink capacity is of 89 voice users per cell or 11 data users per cell.

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