Uplink (Reverse Link) Capacity of an Air-Ground W-CDMA System

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Abstract: - In this work, the uplink capacity and the interference statistics are given for an W-CDMA 3-D Air-to-Ground (AG) cellular like network assuming imperfect power control and finite transmitted power. The free space model of propagation is used to calculate the intercellular interference. The uplink capacity has been studied for different frequencies and scenarios. It has been shown that, the effect of rain is to reduce the uplink capacity and the maximum allowable cell radius. Also it is shown that, the frequency of operation should be lower or equal to 2 GHz. For a frequency of operation of 2 GHz, the cell capacity can reach 70 voice users or 46 data users when the cell radius is 350km. The new contribution of the paper is the study of the effect of the imperfect power control and the finite transmitted power on the uplink capacity of the Air-Ground system for different values of outage.

Key-Words: - W-CDMA, Air-Ground communications, Uplink capacity

1 Introduction

Most short to medium range commercial air-to-ground communications take place in the 118 to 137 MHz frequency band using 25 and 8.33 channel bandwidth. Base stations are available either in traditional AM analogue mode, or the new digital modes. Standard base stations are available in 7W, 15W, 25W, or 50W power ranges, for local or remote control. In the near future, other frequency band and other technologies should be used to have higher capacity and diverse services.

W-CDMA (Wideband Code Division Multiple access) has the advantage that it has not any explicit maximum range. Thus, it is possible to use it for long range Air-Ground communications. A three-dimensional cellular system for aeronautical mobile radio communication was proposed in [1] where the 3-D cellular concept and the cell design and frequency assignment were given.

As most cellular systems to date are terrestrial, the reverse link intercellular interference factor has been estimated for propagation path losses that vary according to a 1/d3.5 law, where d is the distance from transmitter to receiver. In the Air-to-Ground (AG) environment, propagation path loss varies according to 1/d2law [2].

The 3-D outside cell interference factor for an air-ground CDMA cellular system was given in [2] where the forward and reverse interference factors have been calculated. In [3], Ahmed et al. computed the reverse link pole capacity of a W-CDMA Air-Ground system. The effect of the finite transmitted power on the reverse capacity was not studied. In [4], the reverse link interference factor has been given. The capacity is calculated for single radius assuming only single service. None of [3] and [4], has taken into account the interference statistics or the effect of the imperfect power control and the finite transmitted power. Thus, the cell capacity given by these works represents the average capacity (with an outage of 50%), far a way from the practical capacity at lower outage probability.

Recent studies in Europe (Project STAR for example), suggest the use of the L band or the C band (around 5 GHz) to deploy new Air-Ground WCDMA communication system.

In this study, we will calculate the uplink (airplane to base station) capacity and the interference statistics of the Air-Ground W-CDMA system as a function of the cell radius for different outage probability assuming imperfect power control, finite transmitted power assuming that the system supports multi-service.

2 Uplink Analysis

The 3-D view of the system under consideration is depicted in Fig. 1 for the case where base stations are ground sites distributed in a uniform cellular pattern on the surface of the earth [2] with antenna height h_1 of about 20m and the mobiles are air craft flying at altitude h_2.

In order to calculate the reverse link capacity at a given outage probability, the interference statistics (mean value and variance) should be calculated.

In the analysis, we assume an imperfect uplink power control and a cell radius R. In the W-CDMA reverse link, only (ε = 15/16) of the received power is used in the detection [5]. The rest of the power is assigned to the reverse link pilot signal.

The effective average (with 50% outage) bit-energy-to-noise-density ratio of the user under consideration is given by:

$$\frac{E_b}{N_o} \approx \frac{G_p \ \varepsilon \ P_r}{E[I]_t} \tag{1}$$

Where

G_p is the processing gain of the user under study,

P_r is the received signal mean power of the user under study,

$E[I]_t$ is the mean value of the total interference power.

The received signal power (P_{rs}) for a given service s measured in dBm is given by:

$$P_{rs} = P_{ts} + G_t + G_r - L_{path} \tag{2}$$

Where

- P_{ts} is the maximum transmitted power (dBm) for a given service,
- G_t is the gain of the transmitting antenna (dB),
- G_r is the gain of the receiving antenna (dB) and
- L_{path} is the propagation loss (dB) given by:

$$L_{path} = 20 \log_{10}\left(\frac{4\pi}{\lambda}\right) + 10\, n \log_{10}(d) + L_{extra} \tag{3}$$

Where

- d is the distance between the user under consideration and its base station and
- λ is the operating wavelength.
- n is the propagation exponent and
- L_{extra} is the extra path loss due to rain and gases.

For a given service s, the expected value of the intracellular interference power is given by:

$$E[I]_{intra,s} \approx \alpha_s \ e^{(\beta^2 \sigma_c^2)/2} \ N_s \ P_{rs} \tag{4}$$

Where

- α_s is the activity factor of the user in service s,
- ß =(ln10)/10 = 0.23,
- σ_c is the standard deviation of the power control error.
- N_s is the number of users of the service s within any cell.

The expected value of the intercellular interference power is given by:

$$E[I]_{inter,s} = \alpha_s \ \eta_s \ e^{(\beta^2 \sigma_c^2)/2} \ P_{rs} \ \iiint \left(\frac{\rho}{r}\right)^n dV \tag{5}$$

Where η_s is the user's volumetric density for the service s, ρ is the distance between the airplane and its base station and r is the distance between the air plane and the base station of the cell under study. Here the integration is done for all possible points that are in line of sight with the base station of the cell under study.

The expected value of the total interference power $E[I]_{t,s}$ due to a given service s is:

$$E[I]_{t,s} = E[I]_{intra,s} + E[I]_{inter,s} \tag{6}$$

The expected value of the total interference power $E[I]_t$ due to all services that the system supports and the thermal noise P_N of the base station is given by:

$$E[I]_t = \sum_{s=1}^{S} E[I]_{t,s} + P_N \tag{7}$$

From [6], the variance of the intracellular interference power for a given service s is calculated as:

$$\mathrm{var}[I]_{intra,s} \approx N_s \ P_{rs}^2 \left(p\alpha_s - q\alpha_s^2\right) \tag{8}$$

Where p and q are given by [6]:

$$p = e^{2\beta^2\sigma_c^2} \tag{9}$$

$$q = e^{\beta^2\sigma_c^2} \tag{10}$$

From [6] and taking into account our non shadowing and non fading environment, then by changing of the 2D system by our 3D system, the variance of the intercellular interference can be calculated considering only the interference from all users within the volume V within the Line of Sight out of the cell under consideration [2]. Thus, the variance of the intercellular interference power is calculated as:

$$\mathrm{var}[I]_{inter,s} = \eta_s \ P_{rs}^2 \left(p\,\alpha_s - q\alpha_s^2\right) \iiint \left(\frac{\rho}{r}\right)^{2n} dV \tag{11}$$

Thus, the variance of the total interference power for a given service will be:

$$\mathrm{var}[I]_{t,s} = \mathrm{var}[I]_{intra,s} + \mathrm{var}[I]_{inter,s} \tag{12}$$

The variance of the total interference power due to all services that the system supports is given by:

$$\mathrm{var}[I]_t = \sum_{s=1}^{S} \mathrm{var}[I]_{t,s} \tag{13}$$

For a given outage probability, the effective interference power is given by:

$$I_{eff} = E[I]_t + \phi^{-1}(P_{out})\sqrt{\mathrm{var}[I]_t} \tag{14}$$

Where ϕ is the Gaussian tail function (= 2.33 for Pout of 0.01).

The bit-energy-to-noise-density ratio of the user under consideration for any given outage probability is given by:

$$\left[\frac{E_b}{N_o}\right]_{P_{out}=X\%} \approx \frac{G_{ps} \ \varepsilon \ P_{rs}}{\left[I_{eff}\right]_{P_{out}=X\%}} \tag{15}$$

3 Results

In our analysis we assume the following unless other values are mentioned:

- Operating frequency of 1950 MHz (λ = 0.154 m),
- P_t voice = 30 dBm,
- P_t data = 30 dBm,
- G_t = 3 dB,
- G_r = 15 dB,
- h_2-max = 12 km,
- PN = -102 dBm and
- σ_c = 2 dB.
- Rain layer height = 4 km.

Firstly we study the case of voice only service assuming that G_p = 256, $(E_b/N_o)_{req}$ = 6 dB and α = 0.66 [5]. Fig. 2 shows two cases of the uplink capacity. It can be noticed that the average capacity (with 50% outage probability) is 44.5 and 85.0 users for a cell radius of 100 and 350km respectively. For an outage probability of 1%, the uplink capacity is 34 and 70.3 voice users for a cell radius of 100 and 350km respectively.

Next, we study the case of data only service assuming that G_p = 128, (E_b/N_o)req = 3.0 dB and α = 1.0. Fig. 3 depicts two cases of the uplink capacity. Fig. 3 shows that the average capacity (with 50% outage probability) is 29.4 and 56.0 data users for a cell radius of 100 and 350km respectively. For an outage probability of 1%, the uplink capacity is 19.5 and 46.5 data users for a cell radius of 100 and 350km respectively.

Now we study the case when fifteen data user exist in each cell. Fig. 4 portrays two cases of the uplink capacity. It can be noticed that the average capacity (with 50% outage probability) is 20.9 and 61.2 voice users for a cell radius of 100 and 350km respectively. For an outage probability of 1%, the uplink capacity is 12.0 and 47.8 voice users for a cell radius of 100 and 350km respectively. Fig. 5 shows the mixed capacity of the cell assuming a cell radius of 350km and an outage probability of 1%.

Next we study the case when we have a general heavy rain with extra attenuation of 0.1 dB/km [7]. Fig. 6 shows two cases of the uplink capacity. It demonstrates that the average capacity (with 50% outage probability) is 83.6 users for a cell radius of 350km. For an outage probability of 1% and a cell radius of 350km, the uplink capacity is 69.0 voice users. Comparing the results of Fig. 2 and 6, it can be deduced that the effect of the heavy rain on the uplink performance is very small for a frequency of operation of 2 GHz or lower.

Next we study the case of voice users only when the frequency of operation is 5 GHz. Fig. 7 shows two cases of the uplink capacity. It can be noticed that the average capacity (with 50% outage probability) is 44.4 and 78.6 voice users for a cell radius of 100 and 350km respectively. For an outage probability of 1%, theuplink capacity is 33.7 and 64.4 voice users for a cell radius of 100 and 350km respectively.

We study the case when the frequency of operation is 5 GHz assuming a general moderate rain with extra attenuation of 0.1 dB/km [7]. Fig. 8 shows two cases of the uplink capacity. The maximum average capacity (with 50% outage probability) is 70 voice users for a cell radius of 310km. For an outage probability of 1%, the uplink maximum capacity is 56.6 voice users for a cell radius of 310 km. For a cell radius higher than 310 Km, the uplink capacity reduces with the increment of the cell radius. Comparing the results of Fig. 7 with the results of Fig. 8, it can be noticed that rain has a grand effect on the uplink capacity and the maximum usable cell radius.

Finally we study the case when the frequency of operation is 5 GHz assuming heavy general rain with extra attenuation of 0.5 dB/km [7]. Fig. 9 depicts two cases of the uplink capacity. It can be noticed that the maximum average capacity (with 50% outage probability) is 49.7 for a cell radius of 160km. For an outage probability of 1%, the reverse link maximum capacity is 38.4 voice users for the same cell radius i.e., 160 Km. Comparing the results of Fig. 6 and Fig. 9, it can be noticed that, for a cell radius higher than 150 Km, the uplink capacity with an operating frequency of 1.95 GHz, is higher than the uplink capacity at an operating frequency of 5 GHz.

From the above given results, it can be deduced that, for In Route Air-Ground communication system, the frequency of operation for the suggested Air-Ground communications should be lower than or equal to 2 GHz in order to reduce the effect of rain and fog. The recommended frequency is around to 1.2 GHz in such away that the rain and fog effect is negligible. For the approaching task, a frequency up to 5 GHz can be used to get a cell radius of 100km or lower.

If sectorization is used, then, using three sector per cell, the reverse link capacity can be easily (220%-240%) of the above given capacities [5].

4 Conclusion

The uplink capacity and interference statistics have been calculated. The uplink capacity has been studied for different frequencies and scenarios. It has been shown that, the effect of rain is to reduce the uplink capacity and the maximum allowable cell radius. Frequency of operation should be lower or equal to 2 GHz. For a frequency lower than or equal to 2 GHz, the cell capacity can reach 70 voice users or 46 data users when the cell radius is 350 km.

ACKNOWLEDGEMENTS

The work presented in this paper has been supported by the European Commission under the Sixth Framework Program, Air Traffic Management Area, STREP Project STAR (Contract nº AST5-CT-2006-030824).

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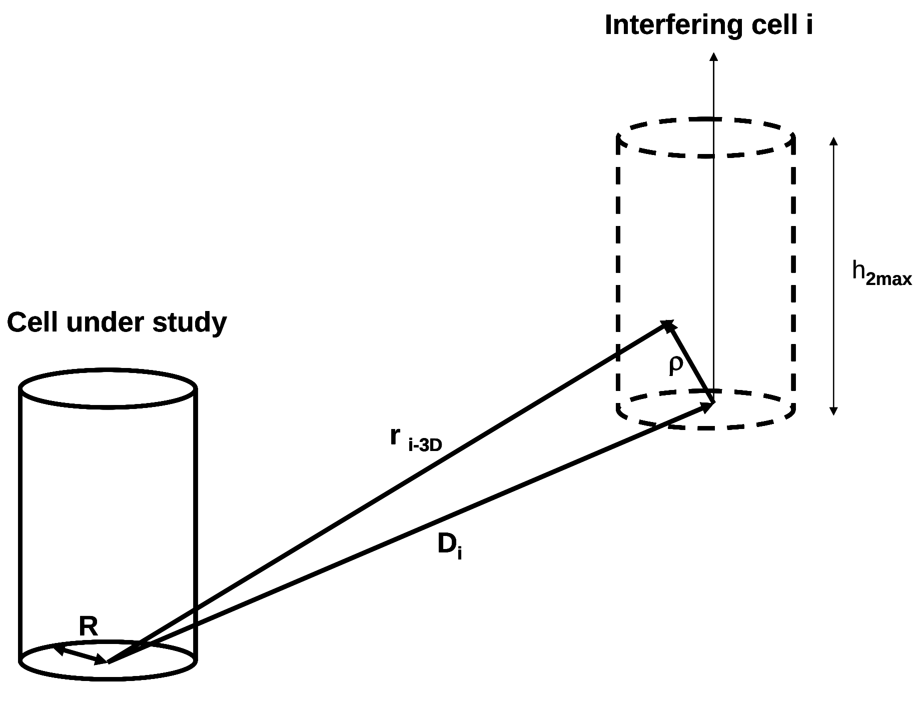

Fig. 1: 3-D view of the W-CDMA Air-Ground communications system.

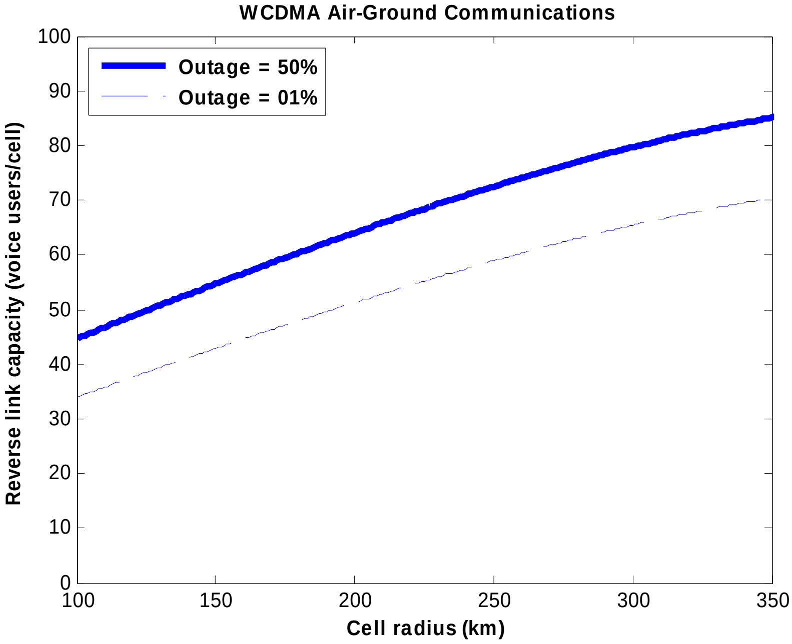

Fig. 2: Reverse link capacity (voice service only) in clear sky.

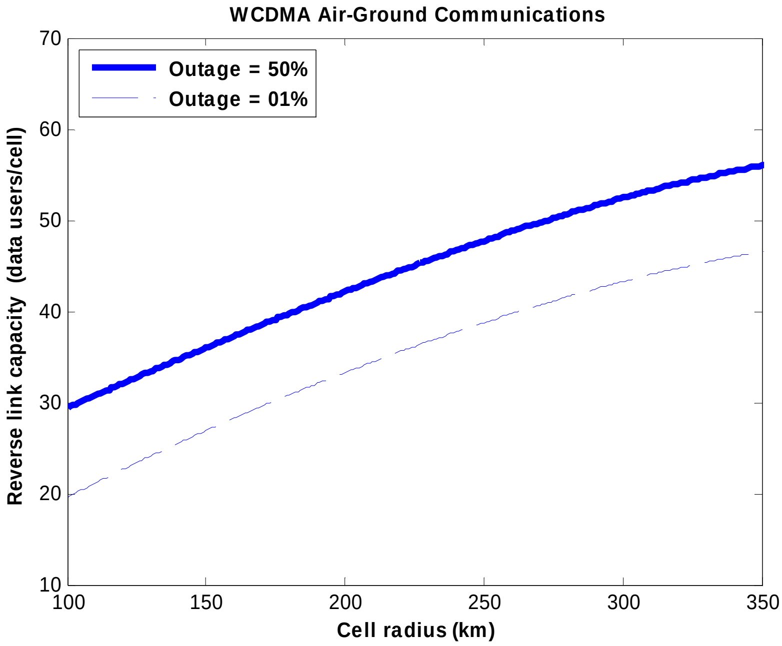

Fig. 3: Reverse link capacity (data only service) in clear sky.

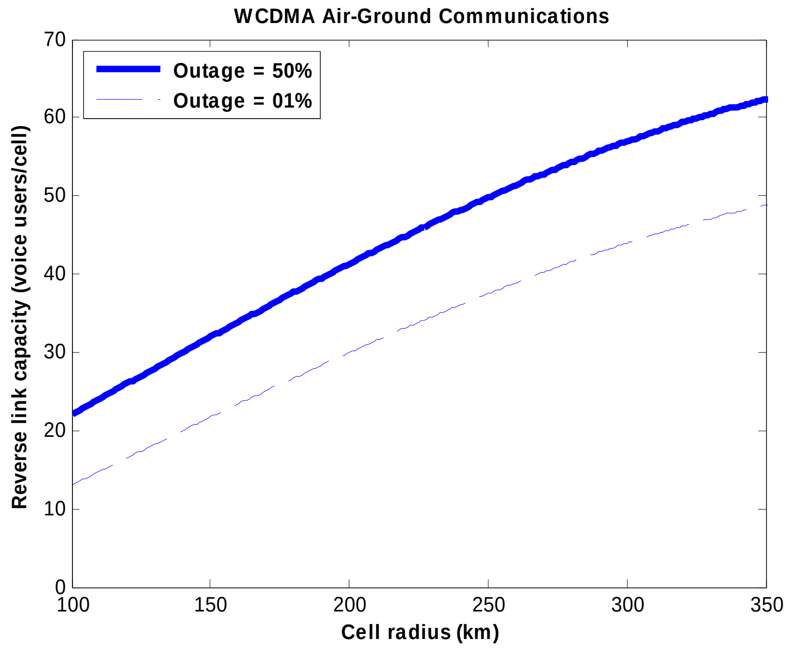

Fig. 4: Reverse link capacity for voice users and fifteen data user/cell in clear sky.

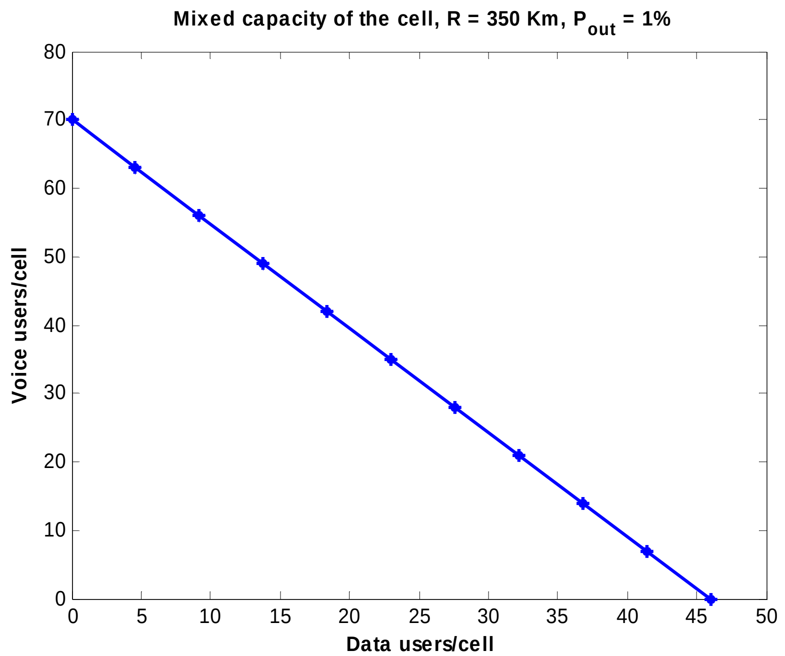

Fig. 5: Cell mixed capacity for R = 350km and an outage probability of 1% in clear sky.

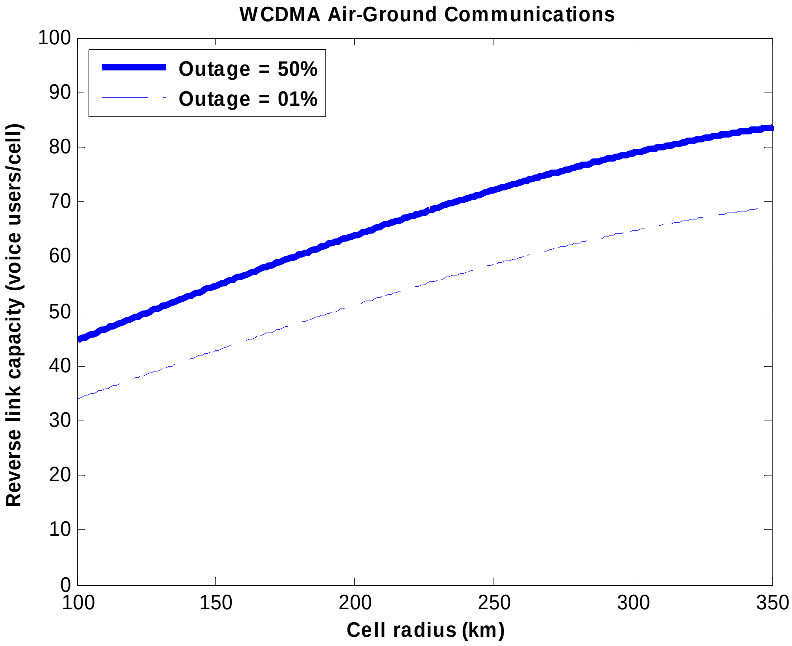

Fig. 6: Reverse link capacity (voice service only) with heavy rain with L_{extra} = 0.1 dB/km.

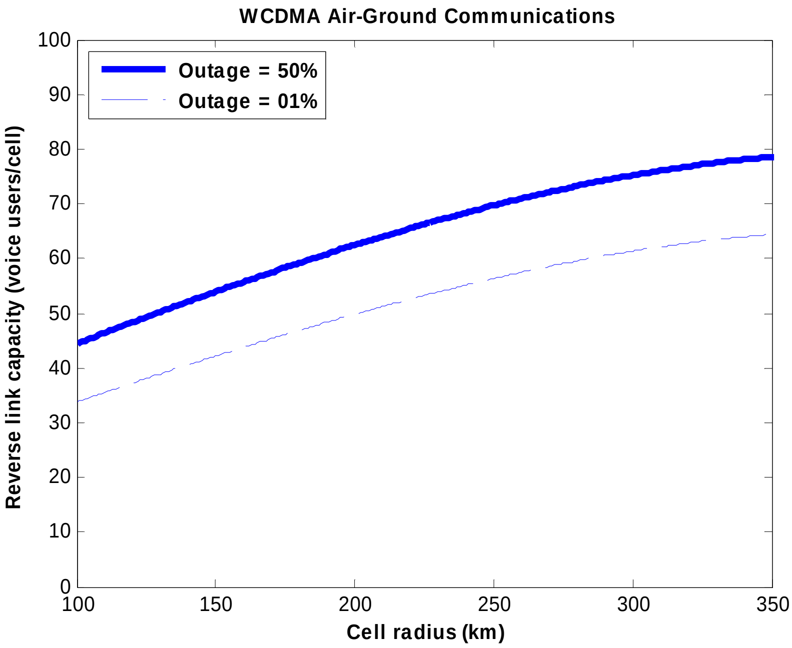

Fig. 7: Reverse link capacity for voice users only with operating frequency of 5 GHz in clear sky.

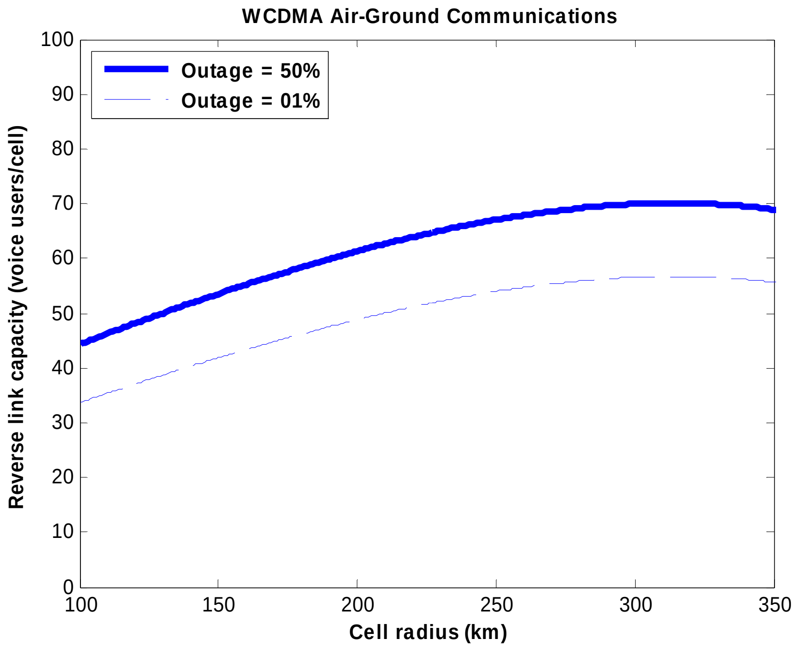

Fig. 8: Reverse link capacity for voice users only with operating frequency of 5 GHz and moderate general rain with L_{extra} = 0.1 dB/km.

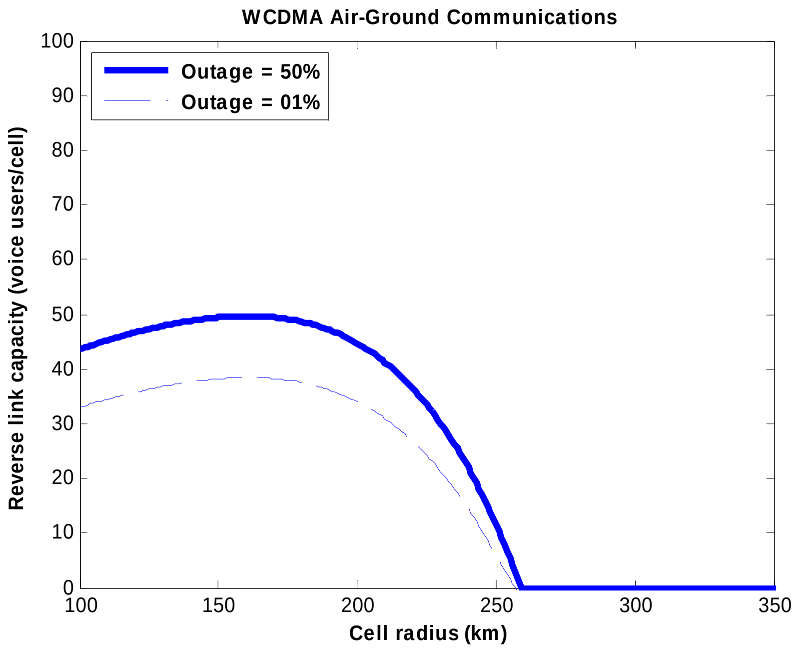

Fig. 9: Reverse link capacity for voice users only with operating frequency of 5 GHz and heavy general rain with L_{extra} = 0.5 dB/km.