On the UMTS Downlink Capacity in (Open Rural and Countryside) Zone Near Deep Space Network (DSN) Installations

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Abstract. *The UMTS macrocell downlink capacity is evaluated for macrocells that operate at the same frequency as the Deep Space Network (DSN) and that are nearby the DSN installations. It has been found that the cell capacity is not affected when the distance between the DSN installations and the macrocell is more than 21 km. For lower distance, the effect is high and the downlink vanishes at a distance less than 2 km when the microcell radius is 1 km. Near the DSN installation, the macrocell radius has to be 1 km or less.*

Keywords

DSN, UMTS, downlink capacity.

1. Introduction

The NASA Deep Space Network - or DSN - is an international network of antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The network also supports selected Earth-orbiting missions.

Standing for "Universal Mobile Telecommunications System", UMTS represents an evolution in terms of services and data speeds from today's "second generation" mobile networks. As a key member of the "global family" of the third generation (3G) mobile technologies identified by the ITU, UMTS is the natural evolutionary choice for operators of GSM networks.

DSN equipment operating at S-band has an uplink frequency from 2 110 MHz to 2 120 MHz. The transmitters at three worldwide sites (near Madrid, Spain; Goldstone, USA; and Canberra, Australia) have both 34-meter and 70-meter antennas [1]. It is obvious that the DSN uplink frequency overlapped a part of the frequency band planned for the UMTS downlink 2 110 MHz to 2 170 MHz. Thus, an interference problem arises in the zone nearby the DSN installations.

DSN are sited in places far away from large cities (urban zones). Thus the effect of the DSN on the UMTS system is negligible in urban zones. We assume that the distance between the open rural or the countryside zones macrocells and the DSN installations is less than 50 km.

The aim of this article is to determine the UMTS macrocells downlink capacity of the above-mentioned macrocell types operating in the band 2 110 MHz to 2 120 MHz.

2. DSN Propagation Losses under Normal Conditions

DSN normal propagation loss is understood as the loss that occurs all the times and that dominates most of the time. The loss includes two parts: free-space loss and the spherical earth diffraction loss. Under normal conditions, the total loss is a combination of both [1].

2.1 Free Space Loss

The free space loss L_{fs} [dB] is given [1] as

$$L_{fs} = 92.45 + 20\log f + 20\log d \tag{1}$$

where f is the frequency of the transmitted signal [GHz] and d is the distance between the transmitter and the receiver [km].

2.2 Spherical Earth Diffraction Loss

The additional transmission loss due to the diffraction over the spherical earth L_{ds} [dB] is defined [1] as

$$L_{ds} = F(X) - (G_{h1} - G_{h2}) \tag{2}$$

where

$$X = 22 f^{1/3} a_e^{-2/3} d \tag{3}$$

and G_{h1} is the transmitter antenna height gain [dB], G_{h2} is the receiver antenna height gain [dB], a_e is the equivalent earth radius [km]. The distance term [1] is given by

$$F(X) = 17.6X - 10\log(X) - 11\,. \tag{4}$$

The height gain terms G_{h1} and G_{h2} are given by equations (11), (11a) of [2] and (3.11.8) of [3] . When f is 2.11 GHz, the transmitter antenna height above the ground is 37 m, the mobile receiver antenna height is 1.5 m, X = 0.068 d, G_{h1} =14.8 dB [1], and G_{h2} = -17.0 dB.

2.3 Total DSN Interference

The total path loss L_{DSN} [dB] till the user under consideration [1] is given by

$$L_{DSN} \approx L_{fs} + L_{ds}\,. \tag{5}$$

Thus the total DSN path loss L_{DSN} in linear unit is given by

$$L_{DSN} = 10^{L_{DSN}[dB]/10}\,. \tag{6}$$

The total DSN interference power is defined as

$$P_{int}(DSN) = P_{DSN}\,G_{DSN}\,G_2 / L_{DSN} \tag{7}$$

where P_{DSN} = 20 kW is the DSN transmitted power, G_{DSN} = = -10 dB is the DSN antenna gain toward the earth surface [1], G_2 = 0 dB is the mobile receiver antenna gain [1] for the circular polarization.

3. Macrocellular Loss

We assume the base station antenna height h_1 = 30 m and the effective antenna gain is 15 dB (three sectors). The macrocells are assumed to exist in open rural or countryside zones.

The propagation loss exponent n [4] is given by

$$n = 4.49 - 0.655\ \log(h_1)\,. \tag{8}$$

3.1 Open Rural Zone Macrocellular Loss

For this case, propagation loss between the base station and the user under consideration L_{rural} [dB] is [4]

$$\begin{aligned} L_{rural} = \ & 46.3 + 33.9\log f_{MHz} - 13.82\log h_1 + \\ & + (44.9 - 6.55\log h_1)\log R_{km} - K_{rural} \end{aligned} \tag{9}$$

where f_{MHz} is the frequency used in MHz, R_{km} is the macrocell radius in km, and

$$\begin{aligned} K_{rural} = \ & 4.78\ (\log f_{MHz})^2 - 18.33\log f_{MHz} + \\ & + 40.94 \end{aligned} \tag{10}$$

The propagation loss L is defined as the loss between two isotropic antennas.

3.2 Countryside Zone Macrocellular Loss

For this case, the propagation loss between the base station and the one under consideration is given by [4]

$$\begin{aligned} L_{c.s} = \ & 46.3 + 33.9\log f_{MHz} - 13.82\log h_1 + \\ & + (44.9 - 6.55\log h_1)\log R_{km} - K_{c.s} \end{aligned} \tag{11}$$

$$\begin{aligned} K_{c.s} = \ & 4.78(\log f_{MHz})^2 - 18.33\log f_{MHz} + \\ & + 35.94 \end{aligned} \tag{12}$$

4. The Macrocell Capacity

We assume that the user under consideration is at the intersection of three macrocells (worst case condition). To calculate the ratio E_b/N_0, we assume the following consternates:

- $P_{st}(max)$ = 20 W [5], where $P_{st}(max)$ is the base station maximum transmitted power;
- $P_{users}(max)$ = 17 W [5], where $P_{users}(max)$ is the maximum power transmitted to the all users. The difference between $P_{st}(max)$ and $P_{users}(max)$ is due to the pilot signal and the other common channels.
- $P_{su}(max)$ = 0.5 W for voice users [4].
- $P_{su}(max)$ = 2.0 W for data users [4], where $P_{su}(max)$ is the base station maximum transmitted power for one user.

The transmitted power for the user under consideration is given by

$$P_u = \min\left[P_{su}(max), P_{users}(max)/N_u\,\alpha\,F\right] \tag{13}$$

where N_u is the cell capacity, α is the source activity factor and $F \approx 0.5$ is the power control reduction factor [6] .

Since L is calculated between two isotropic antennas, then the desired received signal level P_r between two directive antennas is given by

$$P_r = G_{bs}\,G_2\,P_u / L \tag{14}$$

where G_{bs} is the base station antenna gain.

The total multi-user UMTS interference signal is calculated using

$$\begin{aligned} P_{int}(UMTS) \approx \ & G_{bs}\,G_2\,sect\,\frac{[(1-\phi)+Q]}{L}\,\cdot \\ & \cdot\ \min\left[N_u P_{su}(\max)\alpha F, N_u\,P_{su}\,\alpha\,F\right] \\ & + G_{bs}\,G_2\,sect\,\frac{[(1-\phi)+Q]}{L}\,\cdot \\ & \cdot\left[P_{st}(max) - P_{users}(max)\right] \end{aligned} \tag{15}$$

where $sect$ = 1/3 is the sectorization factor for ideal three sectors, ϕ is the orthogonality factor of the downlink users, and Q is the other cells interference [6] defined as

$$Q \approx 2 + 3\left[\frac{R}{2R}\right]^n + 6\left[\frac{R}{2.62R}\right]^n \tag{16}$$

where R is the cell radius.

Now the total interference power is given by

$$P_{int}(total) = P_{int}(DSN) + P_{int}(UMTS) + Noise \quad (17)$$

where $Noise$ is the mobile receiver noise.

The ratio C/I is given by

$$C / I = P_r / P_{int}(total) \quad (18)$$

and the ratio E_b/N_0 is defined as

$$E_b / N_0 = G_p (C / I) \quad (19)$$

where G_p is the process gain.

The macrocell capacity is calculated by increasing the number of users from one user and calculating E_b/N_0 till it reaches the value $(E_b/N_0)_{req}$. The macrocell capacity will be the maximum number of users for which $E_b/N_0 \geq (E_b/N_0)_{req}$.

5. Numerical Results

We assume the following general case:

- $sect$ = 0.4 for non ideal three sectors;
- ϕ = 0.5 [5];
- N_{rec} = -100 dBm assuming Noise Figure of 7 dB.

First we study the case of voice only users. We assume [4]:

- G_p = 256;
- α = 0.5;
- $(E_b/N_0)_{req}$ = 6 dB.

Fig. 1 shows the open rural zone macrocell downlink capacity as a function of the distance between the user under consideration and the DSN transmitter for three different cell radius (1, 2 and 3 km). For a cell radius of 1 km, we can notice that the capacity is null when the distance is less than 2 km and it increases with the distance. When distance is 17 km or more we get the maximum possible capacity.

Fig. 2 shows the countryside macrocell capacity as a function of the distance between the user under consideration and the DSN transmitter for three different cell radius. For a cell radius of 1 km, we can notice that the capacity is null when the distance is less than 4 km and it increases with the distance. When the distance is 21 km or more we get the maximum possible capacity.

Secondly, we study the case of data only users (UDD 144 kbit/sec). We assume the following [4] .

- G_p = 26.6;
- α = 1;
- $(E_b/N_0)_{req}$ = 2.8 dB.

Fig. 3 shows the open rural zone macrocell capacity as a function of the distance between the user under consideration and the DSN transmitter for three different cell radius. For a cell radius of 1 km, we can notice that the capacity is null when the distance is less than 3 km and it increases with the distance. When the distance is 15 km or more we get the maximum possible capacity.

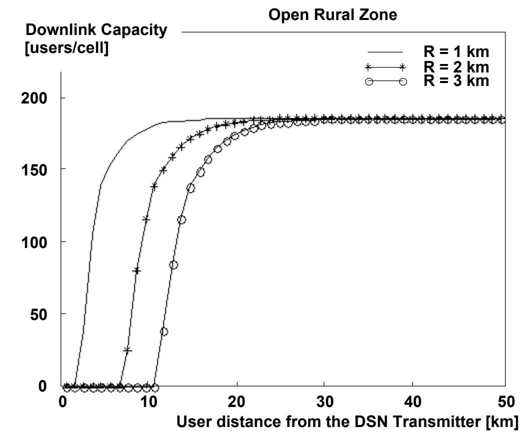

Fig. 1. The open rural zone macrocell performance (voice only users).

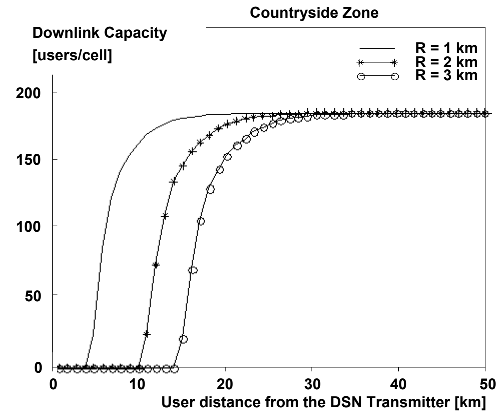

Fig. 2. The countryside zone macrocell performance (voice only users).

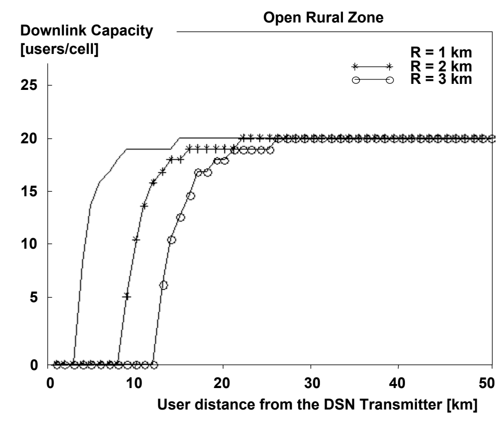

Fig. 3. The open rural zone macrocell performance (data only users 144 kbit/sec).

Fig. 4 shows the macrocell capacity as a function of the distance between the user under consideration and the DSN transmitter for three different cell radius. For a cell radius of 1 km, we can notice that the capacity is null when the distance is less than 5 km and it increases with the distance.

When the distance is 18 km or more we get the maximum possible capacity

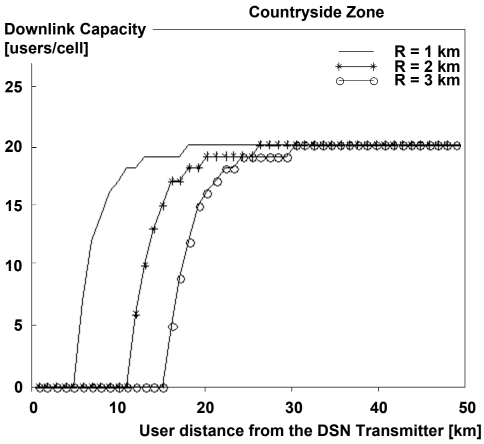

Fig. 4. The countryside zone macrocell performance (data only users 144 kbit/sec).

6. Conclusion

The UMTS downlink capacity has been calculated for open rural and countryside zones near to DSN installations. It has been found that the downlink capacity vanishes very near to the DSN transmitter. At a distance of 2 km for the open rural zone macrocells (voice users case) and at a distance of 4 km for countryside macrocells (voice users case), the capacity begins to increase from zero when the cell radius is 1 km. At a distance of 21 km or more, the DSN effect is null. At a distance of 3 kilometers for the open rural zone macrocells (data users case), and at a distance of 5 km for countryside macrocells (data users case) the capacity begins to increase from zero when the cell radius is 1 km. At a distance of 18 km or more, the DSN effect is null. Near the DSN installation, the macrocell radius has to be 1 km or less.

Acknowledgments

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