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Adjacent Band Interference from San Diego Area Transmitters to Goldstone Deep Space Network Receivers Near 2300 Megahertz

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The Federal Communications Commission (FCC) has recently granted a commercial company a license to potentially deploy its wireless Internet system in the San Diego area in the 2300- to 2305-MHz frequency range. Each of several base station emitters would transmit a relatively strong effective isotropic radiated power (EIRP) (about 50 W). The frequency band is immediately above the band (2290 to 2300 MHz) used by NASA Deep Space Network (DSN) receiving stations at Goldstone, California. A potential interference problem to DSN receivers thus exists through some anomalous propagation modes, such as tropospheric ducting and rain scattering, and interference must be kept under a very small percentage of time (0.001 percent), as required by NASA deep-space missions. In this article, we have estimated the effects of interference from the wireless Internet system to Goldstone receivers. The calculation results show that at 2300 MHz the interference received by the DSN could exceed the DSN protection level up to 0.1 percent of the time for ducting propagation. For rain scattering, this could occur up to 2.3 percent of the time. At 2290 MHz, due to the transmitter spectrum, interference through either mode is below the DSN protection level. Interference through terrain diffraction will suffer very large attenuations at both frequencies. After considering that in the middle of the path there is a tall mountain peak that largely blocks the surface ducting and direct illumination of rain clouds, the interference generated by the wireless system emitters and propagated through either mode is not likely to exceed the DSN receiver protection level more than 0.001 percent of the time.

I. Introduction

Recently, the Federal Communications Commission (FCC) Office of Engineering and Technology issued an experimental license to a California company to test market a wireless Internet system in the San Diego area at 2300 to 2305 MHz [1]. The license, granted in April but only recently made public by the FCC, is good for 2 years. However, the license does not guarantee that the company will actually install and operate the proposed network. The FCC license allows the company to deploy its wireless Internet

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[1] Communications Systems and Research Section.

[2] DSMS Plans and Commitments Program Office.

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technology using up to 3000 "market trial" participants with portable units and up to 50 base-station nodes, each with a maximum peak effective isotropic radiated power (EIRP) of 50 W. The 2300- to 2305-MHz band will accommodate up to eight 600-kHz channels. Each time division duplex (TDD) channel supports up to six simultaneously transmitting subscribers with a maximum downlink (to the subscriber) data rate of 1 Mb/s and a maximum uplink (from the subscriber) data rate of 300 kb/s.

The system is an end-to-end broadband wireless solution, connecting end users' devices to content/service providers and connecting businesses to their customers, suppliers, and employees [2]. End users employ a company-enabled device that wirelessly transmits and receives the data traffic to and from base stations. This traffic is transported over a wide area network and routed through this network to the user's service provider of choice.

The experiment will be conducted within a 56-km (35-mile) radius of San Diego. Market trial users will be equipped with laptops and wireless modems that operate at a maximum EIRP of 1.3 W. The company says it will make clear to participants that the system is experimental and temporary.

The company chose the 2300- to 2305-MHz band for its propagation characteristics and because it is near frequencies under consideration for so-called third-generation, or "3G," services. The band has not been allocated for a primary use and thus is not heavily encumbered with existing users.

Thus, some serious concerns arise, because this frequency band is immediately adjacent above the band (2290 to 2300 MHz) used for NASA Deep Space Network (DSN) weak downlink reception at Goldstone. Because no guard band is possible between the company's and NASA's bands, if the frequency spectrum used by the company is not a sharp enough cutoff at 2300 MHz, it may cause interference to NASA DSN receivers. Even though Goldstone is 219 km distant from the north boundary of a 56-km radius around San Diego and there is no direct line-of-sight link (as shown in Fig. 1), the interference signals from the many transmitters may still reach the DSN receivers through anomalous propagation modes such as tropospheric ducting and rain scattering at a relatively small percentage of the time.

In the company's statement of protection to NASA DSN receivers,[3] four types of interference paths are mentioned: direct satellite transmissions, aircraft transmissions, aircraft reflection, and direct terrestrial paths over intervening terrain to Goldstone. Other types of interference paths were not mentioned in their study. Actually, except for direct coupling within a line of sight between the receiving Earth station and the transmitters, interference signals can also propagate over the horizon through diffraction, surface or elevated ducting, rain scattering, and the tropospheric scatter mechanism [3]. These mechanisms can cause the interference signals to propagate with significantly low attenuation as to be troublesome. The diffraction propagation mechanism contributes only over relatively short distances (<200 km, not considered in this article), while coupling through rain scattering becomes less effective beyond the 300-km range. Ducting propagation effects, however, remain important over a wider range (~500 km). Interference by tropospheric scatter is generally too low to be considered here. In this article, we will use the procedures recommended by International Telecommunication Union (ITU) documents [3–7] to investigate the possibility of interference from San Diego area transmitters to Goldstone receiving stations through these propagation modes.

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[3] ArrayComm, Exhibit 1 document, November 1999.

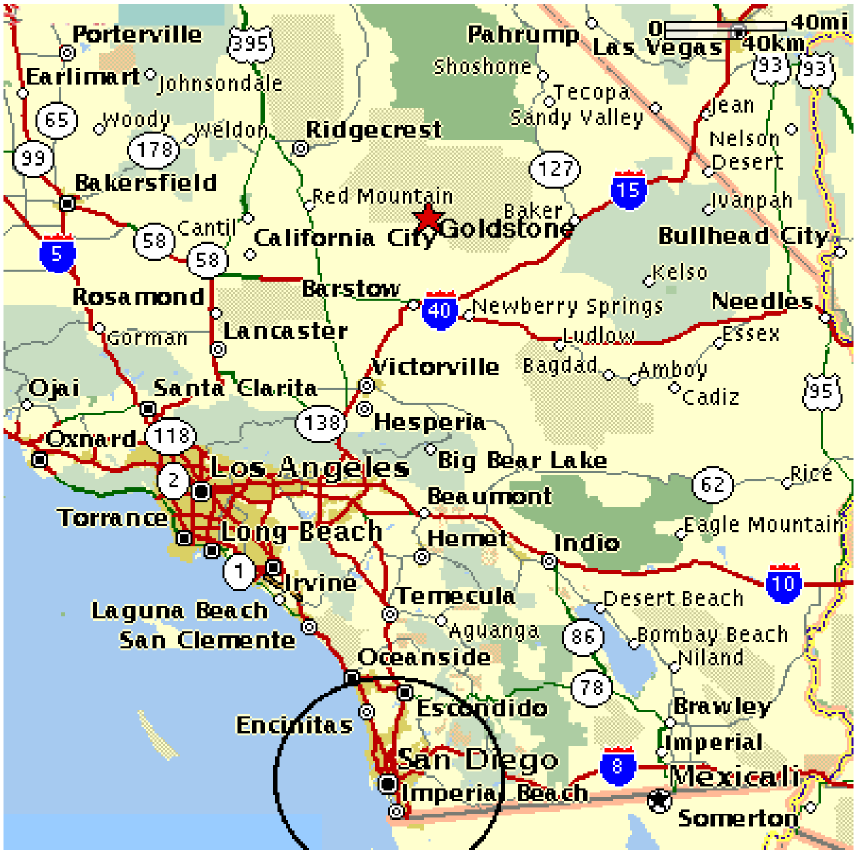

Fig. 1. A map showing NASA's Goldstone DSN location (red star) and the San Diego wireless Internet experimentation area. It is about 219 km between Goldstone and the northern boundary of a 56-km radius around San Diego (black circle).

II. System Parameters

The parameters we used are discussed in the following subsections.

A. System Base Transmitters

Each transmitter[4] has a complicated power output system. Based on our understanding, the system uses a smart antenna, which basically is an antenna array. The smart antenna will direct the transmitted signal intended for a particular user to that user. An unintended user will see very little of that signal.

Because the location of a subscriber device is generally unknown, conventional wireless systems broadcast energy throughout a cell or sector, creating substantial RF interference to unintended receivers. A base station employed with a smart antenna (so-called IntelliCell-enabled) uses information obtained during reception to dynamically direct energy to the desired subscriber terminal, thus substantially reducing RF interference in the surrounding sector. The combination of intelligent reception and directed transmission allows for a far more favorable frequency reuse pattern in the network, which translates into greater capacity and lower costs, as shown in Fig. 2.

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[4] M. Goldburg, personal communication, ArrayComm, provided information regarding the i-burst field experiment in San Diego, California, September 2000.

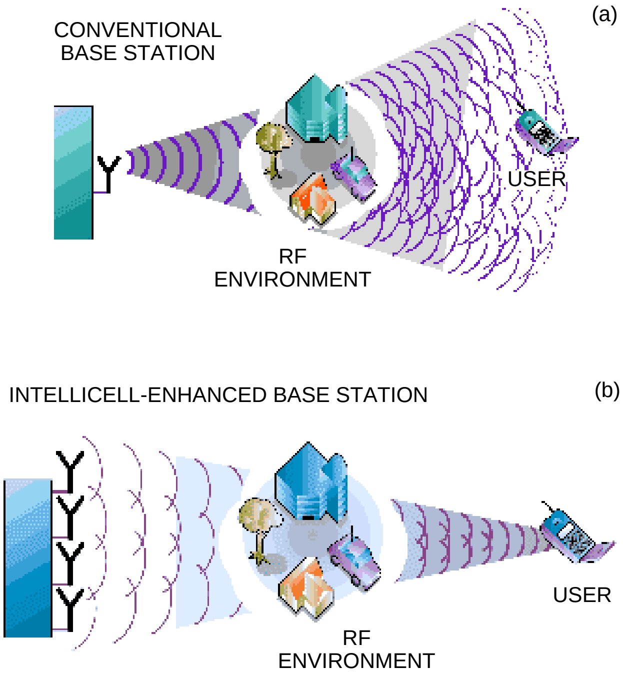

Fig. 2. A comparison of signal power coverage from (a) a conventional antenna and (b) a smart antenna used by the company's experiment in the San Diego area (figure courtesy of ArrayComm).

Each base emitter has a 50-W peak EIRP (17 dBW) in the 2300- to 2305-MHz band. The signal bandwidth is 500 kHz. Thus, the in-band directional power spectral density (PSD) is 50 W/500 kHz = 17 dBW − 57 dB = −40 dBW/Hz or −10 dBm/Hz for its EIRP PSD.

Each base emitter uses 9 high-power amplifiers (HPAs) in the array. Each HPA has power of −9 dBW (+21 dBm). Assuming that there is a 5-dB cable/connector loss between the power amplifier and the array elements, the total emitter power output is $P_t = -9 + 9.5 - 5 = -4.5$ dBW (+25.5 dBm). The emitter maximum antenna gain at boresight points ∼5 deg below the horizon. Thus, we have

$$
\begin{aligned}
P_t &= \text{total HPA} = +25.5 \text{ dBm} \\
\text{antenna gain} &= 21.5 \text{ dBi (boresight)} \\
\text{beamwidth} &= \text{approximately } \pm 7 \text{ deg (for 50 base stations uniformly spread over a 360-deg azimuth;} \\
&\quad \text{two base stations could point to Goldstone simultaneously)} \\
\text{EIRP} &= 47.0 \text{ dBm (boresight)} \\
\text{bandwidth} &= 500 \text{ kHz} = 57 \text{ dB-Hz} \\
\text{PSD} &= -10 \text{ dBm/Hz (boresight)}
\end{aligned}
$$

At 2300 MHz and at the horizon, there is a −5 dB antenna gain roll-off relative to the boresight and a −5 dB power spectral roll-off relative to the peak first channel power. Thus,

$$
\begin{aligned}
P_t &= 20.5 \text{ dBm} \\
\text{antenna gain} &= 16.5 \text{ dBi (horizon)} \\
\text{EIRP} &= 37.0 \text{ dBm (horizon)} \\
\text{PSD} &= -20 \text{ dBm/Hz (horizon)}
\end{aligned}
$$

At 2290 MHz, there is a −39.5 dB power spectral roll-off relative to the peak power. Thus,

$$
\begin{aligned}
P_t &= -14.0 \text{ dBm} \\
\text{antenna gain} &= 16.5 \text{ dBi (horizon)} \\
\text{EIRP} &= 2.5 \text{ dBm (horizon)} \\
\text{PSD} &= -54.5 \text{ dBm/Hz (horizon)}
\end{aligned}
$$

This article assumes two emitters of the maximum number of 50 base stations are simultaneously pointed to the Goldstone DSN receiver.

B. NASA DSN Receivers [8,9]

A 70-m antenna at 2.3 GHz (S-band) has a peak gain of +63 dBi at boresight and a −10 dBi backlobe gain. At 25 deg off boresight, the antenna has a gain, G_r, of −3 dBi.

DSN antennas have mechanical limits at 6-deg elevation. Low elevation often occurs near the east and west, corresponding to spacecraft rise and set. When the antenna points to the south, it is normally near the peak elevation of the pass, usually above 25 deg.

Furthermore, ducting propagation occurs only when the radio wave has a very small incident angle to the horizon. When the grazing angle of incidence is less than a critical angle (this angle is about a few degrees, say, 3 deg), the wave ray can be trapped by the vertical gradient of duct density. Thus, only the gain of the DSN receiver antenna at the horizon applies to ducting interference. The DSN horizon antenna gain used in this article is the gain at 25 deg below its boresight.

For rain scattering, the interference scattered by the rain cell can be received by the DSN antenna at any elevation angle. Actually, rain-scattered interference power received by any DSN receiver is independent of the receiver's antenna gain.

The protection level (power spectral density) at the receiver input port for the DSN station is −222 dBW/Hz at S-band.

C. Propagation Parameters [3,4]

We have the following parameters:

distance = 275 km from Goldstone (70-m antenna site) to downdown San Diego; 219 km from Goldstone to the 56-km limit north of San Diego

ITU ducting region = A2 (inland) region

ITU rain region = radioclimatic E region

D. User (Subscriber) Transmitters

Subscriber transmitters are low-power wireless devices (each with a maximum EIRP of 1.3 W) and omnidirectional antennas. Assuming that there are the maximum 3000 (34.8-dB) subscriber transmitters in that area, the total EIRP will be 35.9 dBW. Compared to a single base station emitter of 50 W EIRP (17 dBW), the total subscriber power is 18.9-dB stronger than that of a single base station. Assuming no more than 10 percent of all subscribers are simultaneously transmitting, and assuming these are equally spread over the 8 available channels, the total subscriber power above is then reduced by 19 dB. Thus, the subscriber total effective power (in any direction) is comparable to a single base station beam assumed to be pointed to Goldstone.

III. Preliminary Results

Using available ITU models, we have calculated propagation losses and interference power through ducting, rain scattering, and terrain diffraction losses.

A. Transhorizon Ducting (Mode 1) [3–5]

For transhorizon ducting propagation along the great circle of the Earth, the transmission loss, L_1, is a function of p, the percentage of time of a weather condition:

$$L_1(p) = 120 + 20 \log f + \gamma(p) d_1 + A_h \text{ dB} \tag{1}$$

Unlike a two-dimensional free space, ducting propagation has a one-dimensional loss due to tropospheric layer entrapment. In Eq. (1), $A_h = 7.5$ dB is a loss for ducting coupling to the duct, and $\gamma(p)$ is ducting attenuation, a function of percentage of time of weather, where

$$\gamma(p) = 0.01 + C_1 + C_2 \log f + C_3 p^{C_4} \tag{2}$$

C_1, C_2, C_3, and C_4 are four parameters. Their values depend on which climatic zone one is in. Corresponding to a smaller p, there is a smaller loss L_1, or stronger interference. Duct thickness is usually several hundreds of meters.

B. Rain Scattering (Mode 2) [3–5]

For the rain-scattering transmission loss L_2, a different definition from that for ducting loss is used. The received interference power, P_r, is independent of the receiver's antenna gain:

$$L_2(p) = \frac{P_t}{P_r} \tag{3}$$

Transmission loss due to rain scattering is [3–5]

$$L_2(p) = 168 + 20 \log d_2 - 20 \log f - 13.2 \log R - G_t + \Gamma \text{ dB} \tag{4}$$

where R is the rain rate, a function of percentage of time of a weather condition; G_t is transmitter antenna gain; and Γ is

$$\Gamma = \frac{631 k R^{\alpha}}{\sqrt{R}} 10^{-(R+1)^{0.19}} \text{ dB} \tag{5}$$

where k and α are two coefficients related to the radio wave frequency.

Figure 3 shows the calculated propagation losses for ducting and rain-scattering modes as a function of percentage of time, $p\%$. Larger propagation losses—thus smaller interference powers—occur for large time percentages. It is at the low time percentages, e.g., 0.001 percent, that suitability for weak-signal DSN downlink reception is determined. As a reference, we have also shown the free space (FS) loss for line of sight, even though there is no such direct link. At these frequency bands, atmospheric gas attenuation has been neglected [10].

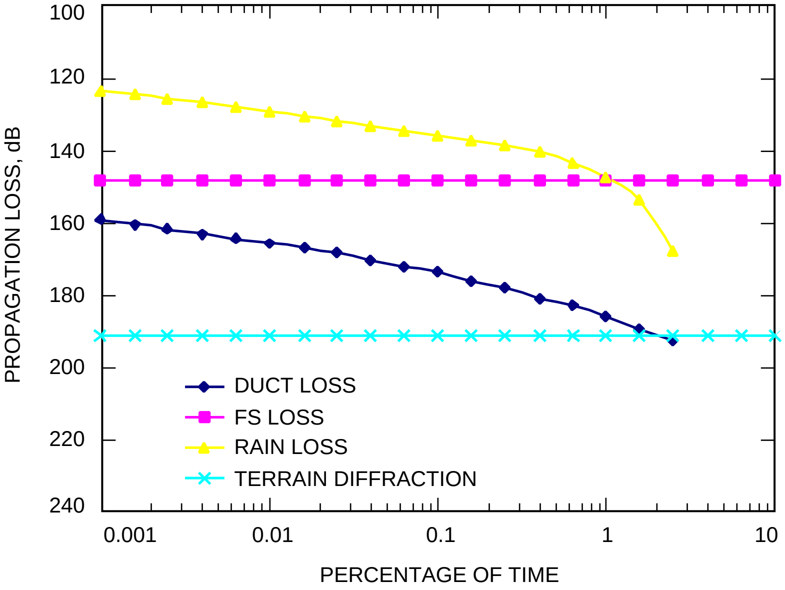

Fig. 3. Propagation losses through ducting, rain scattering, free space, and terrain diffraction over a 219-km distance between Goldstone and 56 km north of San Diego.

C. Terrain Diffraction Loss [6]

Even though the terrain diffraction becomes less important when the propagation distance is greater than 200 km, we have still calculated this loss for comparison purposes. Figure 4 shows a surface terrain profile between Goldstone (left side) and San Diego (right side) that is a topographic cut of Goldstone 185-deg azimuth from the north. It is about 275 km between Goldstone and downdown San Diego, while it is about 219 km from Goldstone to 56 km north of San Diego. There is a significant mountain range (San Bernardino Mountains) in the middle with a height of about 2528 m (note that different scales have been used for the vertical and horizontal dimensions for the figure). This topographic feature may be simplified into an ideal single knife edge. To calculate the diffraction loss across the knife edge, we need to consider the geometric parameters first. The angular distance, θ, is defined as the angle in radians between horizon rays from transmitter T and from receiver R in the great circle plane and is also the minimum diffraction angle:

$$\theta = \frac{d}{a_e} + \theta_{et} + \theta_{er} \tag{6}$$

where d is the distance between the transmitter and receiver at sea level and α_e is the effective Earth radius (8931 km). The horizon ray elevation angles relative to the transmitter, θ_{et}, and the receiver, θ_{er}, may be computed using the following equations:

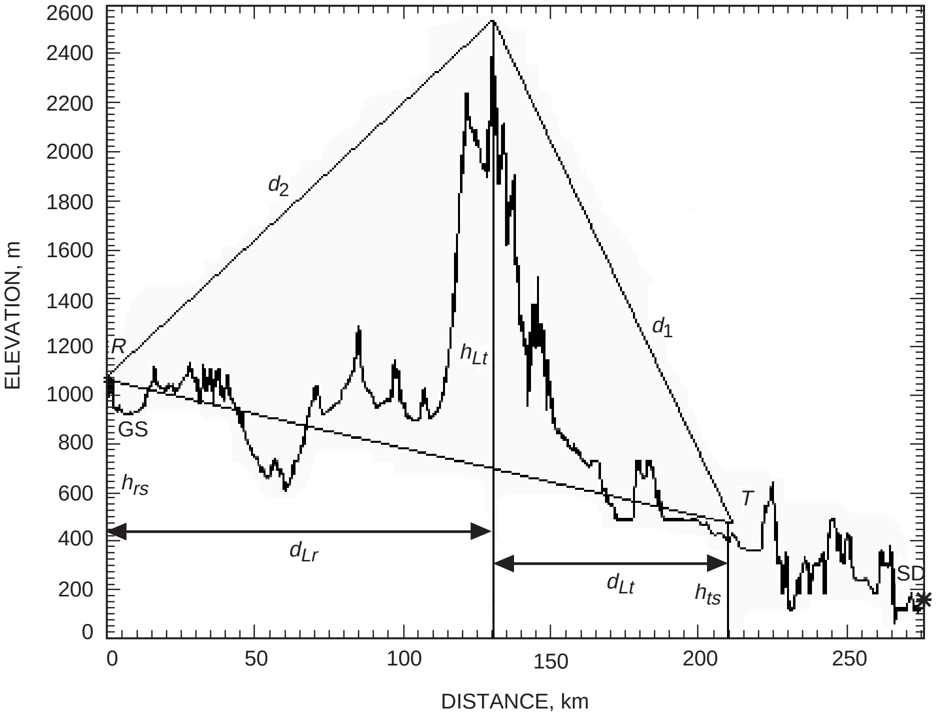

Fig. 4. A topographic profile between Goldstone (GS) and San Diego (SD). It is about 275 km between Goldstone and downtown San Diego and about 219 km from Goldstone to 56 km north of San Diego. A big mountain range (San Bernardino Mountains) is in between the transmitters (*T*) and receivers (*R*) with a height of 2,528 m. This terrain profile may be simplified into an ideal single knife-edge diffraction. The mountain tops could also block most surface ducts and direct illumination of rain clouds. Thus, the interference caused by both mechanisms would be significantly reduced.

$$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a_e} \tag{7}$$

and

$$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a_e} \tag{8}$$

where h_{Lt}, h_{Lr} are the elevations of horizon obstacles and h_{ts}, h_{rs} are elevations of transmitting and receiving antennas, respectively, all above mean sea level (AMSL). The transmitter antennas are taken to be 20 m above the ground, while the receiving antenna in Goldstone is taken to be 37 m above the ground. All parameters for this mountain peak are listed in Table 1.

Table 1. Parameters for a single knife edge (San Bernardino Mountain).

d, km	d_1, km	d_2, km	d_{Lt}, km	d_{Lr}, km	h_{ts}, km	h_{rs}, km	h_{Lt}, km	h_{Lr}, km
219	90.5	133.2	88.5	130.2	0.383	1.002	2.528	2.528

For a single knife edge, parameter ν is defined as

$$\nu = \theta \sqrt{\frac{2d_1 d_2}{\lambda d}} \tag{9}$$

where wavelength $\lambda = 1.30 \times 10^{-4}$ km for the radio wave at S -band (2300 MHz). The diffraction loss for a single knife edge is

$$J(\nu) = 6.9 + 20 \log \left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1 \right) \text{ dB} \tag{10}$$

Finally, we obtain $\theta = 0.0486$ rad, $\nu = 43.75$, and $J(\nu) = 45.74$ dB.

In addition, the free space loss, L_b, is

$$L_b = 32.45 + 20 \log f + 20 \log d \tag{11}$$

Thus, the total diffraction loss for this path will be $L_d = L_b + J(\nu) = 191.5$ dB. Anomalous terrain diffraction loss for a very small percentage of time ($p < 0.1$ percent) is actually only a few dB less than this number. This loss is much larger than the other two anomalous losses (duct and rain); thus, ducting and rain scattering are the determining factors for the DSN.

D. Interference Power [7]

We have calculated the interference PSD received by Goldstone through the three modes. For the ducting and terrain diffraction modes, received interference powers, P_r, are

$$P_r = P_t + G_t - L + G_r \tag{12}$$

where P_t is the transmitter power from base-station transmitters and subscriber emitters. For a conservative estimate, here we have assumed that two base stations and one load of subscribers point to the DSN at any time. Thus, the total power emitted will be three times (4.77 dB) that of a single base emitter.

For the rain-scattering mode, interference power is

$$P_r = P_t - L \tag{13}$$

Interference power spectral densities received at 2300 MHz and 2290 MHz, respectively, through ducting, rain scattering, free space, and terrain diffraction are shown in Figs. 5 and 6. In order to know if the received interference powers affect the DSN receiver, we have shown the DSN protection criteria in the figures. The protection level (power spectral density) required for a DSN receiver at S-band is -222 dBW/Hz (-192 dBm/Hz), not to be exceeded for more than 0.001 percent of the time.

We can see from Fig. 5 that, at 2300 MHz, interference PSD received by the DSN from the company's emitters will exceed the DSN's protection level at certain percentages of the time. For ducting propagation, the exceeding occurs 0.1 percent of the time. For rain scattering, this occurs 2.3 percent of the time. At 2290 MHz, interference through both modes is below the DSN's protection level, because the transmitting system power spectral output at this frequency is 34.5 dB lower than at 2300 MHz (39.5 dB lower than the peak power). This will not cause a problem for DSN operation. At both ends of the

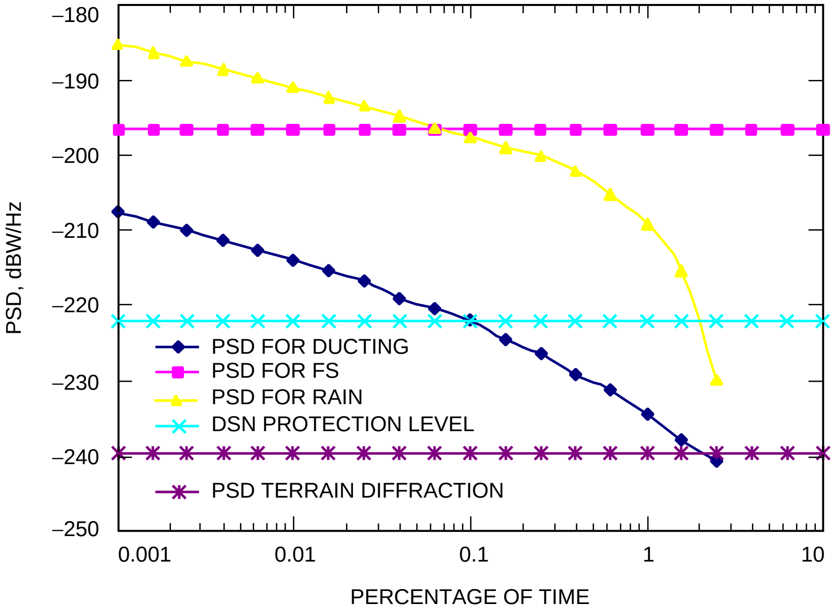

Fig. 5. Interference PSD received by Goldstone 70-m antenna (assuming mainbeam 25 deg off from horizon) through ducting, rain scattering, FS, and terrain diffraction at 2300 MHz from 56 km north of San Diego wireless emitters.

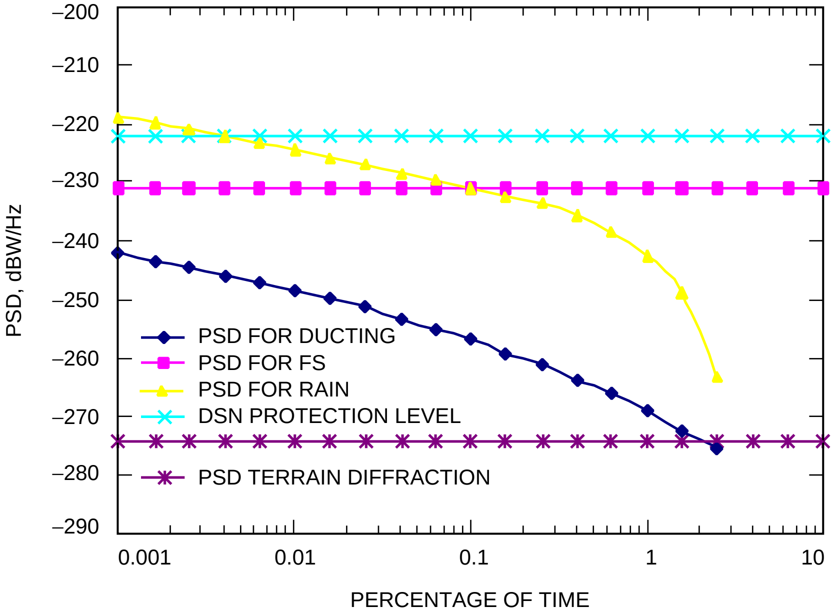

Fig. 6. Interference PSD received by Goldstone 70-m antenna (assuming mainbeam 25 deg off from horizon) through ducting, rain scattering, FS, and terrain diffraction at 2290 MHz from 56 km north of San Diego wireless emitters.

frequency band, interference power through terrain diffraction is far below the protection level. Thus, terrain diffraction will not cause a problem for DSN operation.

Despite the rather high time percentages calculated alone for 2300 MHz, after considering topographic effects, the actual interference caused by ducting and rain scattering is likely to be significantly reduced. The San Bernardino Mountains will interrupt most of the surface ducts. Clouds with heights between 2500 and 3000 m are almost completely blocked from direct illumination. There is no line-of-sight propagating for interference signals scattered by rainfall to either commercial system emitters or the DSN receivers. Thus, the probabilities of interference propagating through ducting and rain scattering also become very low due to the mountain shielding.

IV. Conclusion

Because of the relatively strong power used by the system emitters at 2300 MHz, without considering terrain profiles the system would likely cause significant interference problems to the Goldstone DSN receivers when the Goldstone antenna mainbeam points to the south and at a 25-deg elevation angle. Calculated interference exceeds the DSN protection level by 14.8 dB for ducting propagation and by 36.8 dB for rain scattering at 0.001 percent of the time. The interference through terrain diffraction over the knife edge can be ignored. It seems that interference through rain scattering will be the main problem because of its independence of the receiving antenna gain. There is a very high time percentage (2.3 percent) for the protection level being exceeded through rain scattering. DSN operations only allow the interference to be exceeded by 0.001 percent of the time in order to meet mission requirements.

However, after considering mountain shielding effects, the interference caused by both mechanisms (duct and rain) will be significantly reduced. The highly elevated mountain peaks along the path will interrupt most of the surface ducts and also prevent direct illumination of rain clouds. Even though some interference signals can propagate through a hybrid mode (ducting plus mountain-top diffraction, or rain scattering plus mountain-top diffraction), the surface diffraction can cause an additional 30- to 40-dB loss. Thus, interference power after passing the San Bernardino Mountains will very likely be comparable to the DSN protection level.

We also noted that the base stations are equipped with a smart/adaptive antenna system. One important consequence of this is that the average (in an azimuthal sense) radiated power is significantly less than the EIRP. In fact, it is reduced by a factor equal to the number of elements in the antenna array. With a ten-element array, the “average EIRP” would then be 5 W at the rated depression angle rather than the 50 W provided in the direction of an active user. Similarly, on the user return, the gain provided by the base-station antenna array allows the user terminals, which have 0- to 2-dBi omnidirectional antennas, to operate at low power. All of these will cause interference power emitted from the system to be weaker. Thus, we conclude that the interference generated by the system emitters is not likely to exceed the DSN receiver protection level more than 0.001 percent of the time.

Acknowledgments

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