Table 4 gives the results of the same eleven examples but with the average polarization isolation reduced to only 3 dB.

Scenario - Downlink	AMSC (RHC)	Constell'n (LHC)	Ellipsat (RHC)	Globalstar (RHC)	Odyssey (LHC)	Celsat (LHC)	Total
Case 1: Max. PFD (dBW/m2/4kHz)	-142.0	-142.0	-142.0	-142.0	-142.0	-142.0	
Resulting Capacity (# ccts)	1663	773	1397	2442	2407	11389	20072
Case 2: Max. PFD (dBW/m2/4kHz)	-139.0	-139.0	-139.0	-139.0	-139.0	-139.0	
Resulting Capacity (# ccts)	1743	928	1677	2930	2888	13017	24063
Case 3: Max. PFD (dBW/m2/4kHz)	-142.0	-142.0	-142.0	-142.0	-142.0		
Resulting Capacity (# ccts)	1911	844	1525	2865	2826	0	9679
Case 4: Max. PFD (dBW/m2/4kHz)	-139.0	-139.0	-139.0	-139.0	-139.0		
Resulting Capacity (# ccts)	2018	1031	1863	3266	3209	0	11377
Case 5: Max. PFD (dBW/m2/4kHz)	-139.0	-139.0	-139.0	-139.0			
Resulting Capacity (# ccts)	2395	1160	2096	3663	0	0	9316
Case 6: Max. PFD (dBW/m2/4kHz)	-139.0	-139.0	-139.0		-139.0		
Resulting Capacity (# ccts)	2943	1325	2394	0	4123	0	10796
Case 7: Max. PFD (dBW/m2/4kHz)	-142.0	-142.0	-142.0	-139.0	-139.0		
Resulting Capacity (# ccts)	1323	664	1199	4602	4437	0	12124
Case 8: Max. PFD (dBW/m2/4kHz)		-142.0	-142.0	-139.0	-139.0		
Resulting Capacity (# ccts)	0	774	1399	5320	5242	0	12736
Case 9: Max. PFD (dBW/m2/4kHz)			-142.0	-139.0	-139.0		
Resulting Capacity (# ccts)	0	0	1526	5853	5768	0	13147
Case 10:Max. PFD (dBW/m2/4kHz)				-139.0	-139.0		
Resulting Capacity (# ccts)	0	0	0	7314	7208	0	14523
Case 11:Max. PFD (dBW/m2/4kHz)				-139.0	-139.0	-142.0	
Resulting Capacity (# ccts)	0	0	0	6501	6406	13936	26843

<u>Table 4 (cross-polar isolation = 3 dB; available bandwidth = 16.5 MHz)</u>

The eleven example scenarios in the above tables are each described below:

Case 1: All six systems (CDMA applicants + Celsat) are operating at a maximum PFD of -142 dBW/m²/4kHz.

Case 2: All six systems (CDMA applicants + Celsat) increase their maximum operating PFD to -139 dBW/m²/4kHz.

Case 3: Same as Case 1 except that only the five CDMA applicants are operating.

Case 4: Same as Case 2 except that only the five CDMA applicants are operating.

Case 5: Same as Case 4 except that Odyssey is assumed not to be operating.

Case 6: Same as Case 4 except that Globalstar is assumed not to be operating.

Case 7: Same as Case 3 except that Globalstar and Odyssey increase their maximum PFD by 3 dB.

Case 8: Same as Case 7 except that AMSC is assumed not to be operating.

Case 9: Same as Case 7 except that both AMSC and Constellation are assumed not to be operating.

Case 10: Same as Case 7 except that AMSC, Constellation and Ellipsat are assumed not to be operating.

Case 11: Same as Case 10 except that Celsat is assumed to be operating (at -142 dBW/m²/4kHz) in addition to Globalstar and Odyssey (at -139 dBW/m²/4kHz).

5.1.3.3 Collective Combined System Capacities (10.5 MHz Bandwidth)

An analysis was also performed of the system capacities, on a paired basis, when only 10.5 MHz bandwidth is assumed to be available, due to inter-service sharing constraints in the band 1610-1616 MHz. As expected, these results show a reduction in the ratio of 10.5 MHz to 16.5 MHz, or a ratio of approximately 64%.

5.1.4 Uplink Methodology

A similar technique is used to calculate the uplink capacities of the systems as was used for the downlink (see sections 5.1.2 and 5.1.3). However, it is important to note that the factors determining uplink and downlink capacities are not completely identical. The methodology for the uplink capacity calculation is therefore described completely in this section, even though parts of the method are the same as used in the satellites in the same system providing co-coverage, the beams in the areas of overlap should only be counted once.

(F_u) Beam Frequency Re-Use Factor

This parameter is a measure of the degree to which the uplink frequency band is re-used spatially among the beams. The value of this parameter is "N", where frequencies are re-used once in every "N" beams. For example, a system with re-use in every beam has a value of N=1. A system with full frequency re-use in every third beam has a value of N=3.

(G_u) Average Propagation Margin

This is the uplink power margin required, in dB, at any instant in time, averaged over all the users in the CONUS coverage of the system, used to overcome propagation impairments relative to free space. Note that the uplink benefits from a statistical advantage relative to the downlink in this parameter. On the downlink the worst case link, from an interference point of view, will have clear line-of-sight to the satellite, and thus receive the full interfering effect of all the downlink signals. However, on the uplink, the aggregate interference received at the satellite will benefit from the fact that not all interfering uplinks are visible to the victim satellite. Some are shadowed and so the resulting aggregate uplink interference is correspondingly less. A simple model which can be used to calculate this effect (based on a two-state propagation model) is given in Annex 5.3.

(H_u) Average Orbit and Beam Effects

This parameter takes account of the combined effect of uplink range differences and uplink antenna gain contour effects. It is essentially a dB value that is equivalent to the average extra user mobile terminal power required to communicate with the satellite, assuming that all the users are distributed throughout the CONUS coverage, compared to the situation if all those users were located at the optimum location in the coverage area where G/R^2 is at a maximum (G = satellite antenna gain; R = range to the satellite). It accounts for the difficulty of building a perfect satellite antenna.

(J_u) Average Power Control Implementation Margin

This is a dB value which is a result of imperfect uplink power control. It is equal to the average amount by which the link power exceeds the minimum necessary to sustain the link, if power control were perfect.

(K_u) Average Beam Overlap Factor

This takes account of the spillover between uplink beams. It is the ratio, in dB, averaged over all the users throughout the CONUS coverage, of the power arriving in the intended plus adjacent beams to the power arriving in the intended beam only. Its value is highly dependent on the Beam Frequency Re-Use Factor (see item (F_u) above).

5.1.4.2 Uplink Analysis Method

The uplink analysis method can be split into the several parts. The first two, which are system specific, should first be calculated for each system:

(a) Calculate maximum ideal uplink capacity (C_{MIU}), using the following formula:

$$C_{MIU} = (C_u \cdot E_u) / (A_u \cdot B_u \cdot D_u \cdot F_u) \qquad (7)$$

where the letters in the formula correspond to the parameters defined in section 5.1.5.1 above. Note that this equation is valid provided that there is sufficient dynamic range in the handset to cope with the required propagation margin. Annex 5.4 discusses this issue and provides an alternative capacity formula for one possible strategy in the event that there is inadequate dynamic range. All the CDMA applicants (and Celsat) intend to provide adequate dynamic range without resorting to this strategy. Motorola believes that all CDMA applicants (and Celsat) have some dynamic range limitations on capacity.

(b) Calculate reduction from maximum ideal uplink capacity (C_{MIU}), by taking account of the parameters defined in items G_u, H_u, J_u and K_u in section 5.1.5.1 above. These parameters, when each expressed in dB, can be summed to produce the total uplink capacity margin (Δ_U). The maximum realizable uplink capacity (C_{MRU}) can then be derived as follows:

$$C_{MRU} = C_{MIU} / (10\text{^}(\Delta_U/10)) \qquad (8)$$

$$\text{where } \Delta_U = G_u + H_u + J_u + K_u$$

The next stage in the analysis is to derive the uplink capacity graph for each system, which relates the realizable capacity of the system to the maximum operating uplink EIRP areal-spectral density, ε_{au}, for varying amounts of interfering co-polar uplink EIRP areal-spectral density, ε_{iu}, due to other sharing systems. Refer to Annex 5.1 for an explanation of the significance of these parameters. This is calculated as follows:

First it is necessary to calculate the effective thermal noise equivalent uplink EIRP areal-spectral density in a 4 kHz bandwidth, ε_{nu}, which is given by the following equation:

$$\varepsilon_{nu} = (k \,.\, T_s) / 0.00276 \qquad (9)$$

where: k = Boltzmann's constant (= -228.6 dB)
T_s = Satellite receive system noise temperature (typically = 500K or 27.0 dBK)

This equation gives a value for ε_{nu} of -140.0 dBW/m²/4kHz, assuming that T_s is 500K. This is the equivalent uplink EIRP areal-spectral density at the Earth's surface that would be required to produce the satellite receive system noise temperature corresponding to 500K.

The realizable uplink capacity, C_{RU}, of the system, when operating without other interfering systems present, can now be related to the maximum realizable uplink capacity, C_{MRU}, the maximum operating uplink EIRP areal-spectral density, ε_{su}, and the effective thermal noise equivalent uplink EIRP areal-spectral density in a 4 kHz bandwidth, ε_{nu}, by the following equation:

$$C_{RU} = (C_{MRU} \,.\, \varepsilon_{su}) / (\varepsilon_{su} + \varepsilon_{nu}) \qquad (10)$$

The impact of interfering co-polar uplink EIRP areal-spectral density from other co-frequency systems, ε_{iu}, can also be taken into account using the following equation:

$$C_{RU} = (C_{MRU} \,.\, \varepsilon_{su}) / (\varepsilon_{su} + \varepsilon_{nu} + \varepsilon_{iu}) \qquad (11)$$

5.1.5 Uplink Analysis

This section presents the results obtained when the uplink methodology described in section 5.1.4 above is applied to the CDMA applicants' (and Celsat's) proposed MSS systems. The individual system capacity analysis is performed assuming that the full 16.5 MHz RF bandwidth is available to the CDMA systems. The collective combined system capacity analysis is performed for available bandwidths of both 16.5 MHz and 10.5 MHz (contingency in the event that the band 1610-1616 MHz is not usable due to other inter-service sharing constraints).

5.1.5.1 Individual System Capacities

Using the equations given in section 5.1.4.2 above, the maximum ideal uplink capacity, C_{MIU}, and the maximum realizable uplink capacity, C_{MRU}, for the CDMA applicants' (and Celsat's) systems have been calculated, using input data provided by the proponents of the systems. The input data and results are given in Table 5 below:

System Parameter	Units	AMSC	Constell'n	Ellipsat	Globalstar	Odyssey	Celsat
Baseband Bit-Rate	(kBPS)	3.0	4.8	4.8	4.8	4.8	5.0
Channel Activity Factor	(#)	0.40	0.50	0.40	0.50	0.40	0.35
Total RF Bandwidth	(MHz)	16.5	16.5	16.5	16.25	16.5	16.5
Minimum Operating Eb/No	(dB)	4.0	4.0	4.5	4.8	4.5	4.0
Number of Beams in CONUS	(#)	6	10	10	20	16	149
Beam Frequency Re-Use Factor	(#)	1	1	1	1	1	1
Average Propagation Margin	(dB)	2.00	1.70	1.50	1.00	1.30	1.00
Average Orbit & Beam Effects	(dB)	2.50	2.90	2.00	1.29	1.50	1.70
Average Power Control Impl. Mar.	(dB)	1.50	1.50	1.00	1.00	1.00	2.00
Average Beam Overlap Factor	(dB)	1.09	1.00	1.00	1.23	1.25	3.80
Noise Temp. Satellite System	(K)	500	500	500	500	500	500
Maximum Ideal Uplink CONUS Capacity Limit (see Note 1)	(# of ckts)	32,844	27,370	38,482	44,941	48,787	689,394
Maximum Realizable Uplink CONUS Capacity Limit (see Note 1)	(# of ckts)	6,419	5,337	8,584	16,837	16,251	78,861

Table 5 (uplink)

Note 1: It is not intended to operate the systems at these maximum realizable uplink capacity limits. Power level constraints will dictate the individual system power levels and corresponding capacities.

Note 2: Motorola believes that certain values for some of the parameters in Table 5 need to be adjusted to reflect what it considers should be used to operate in real world conditions, and therefore cannot agree with the capacity numbers calculated in the table. See Note below.

Using equation (10) from section 5.1.4.2 above, the realizable uplink capacity of the systems, when operating both in isolation and in the presence of other interfering systems, has been calculated, and the results are given in the Figures 7 to 12 below:

NOTE: Motorola's analysis is reflected in the work of Dr. Peter Monsen dated March 24, 1993. It is assumed that Motorola will include this document in its minority report.

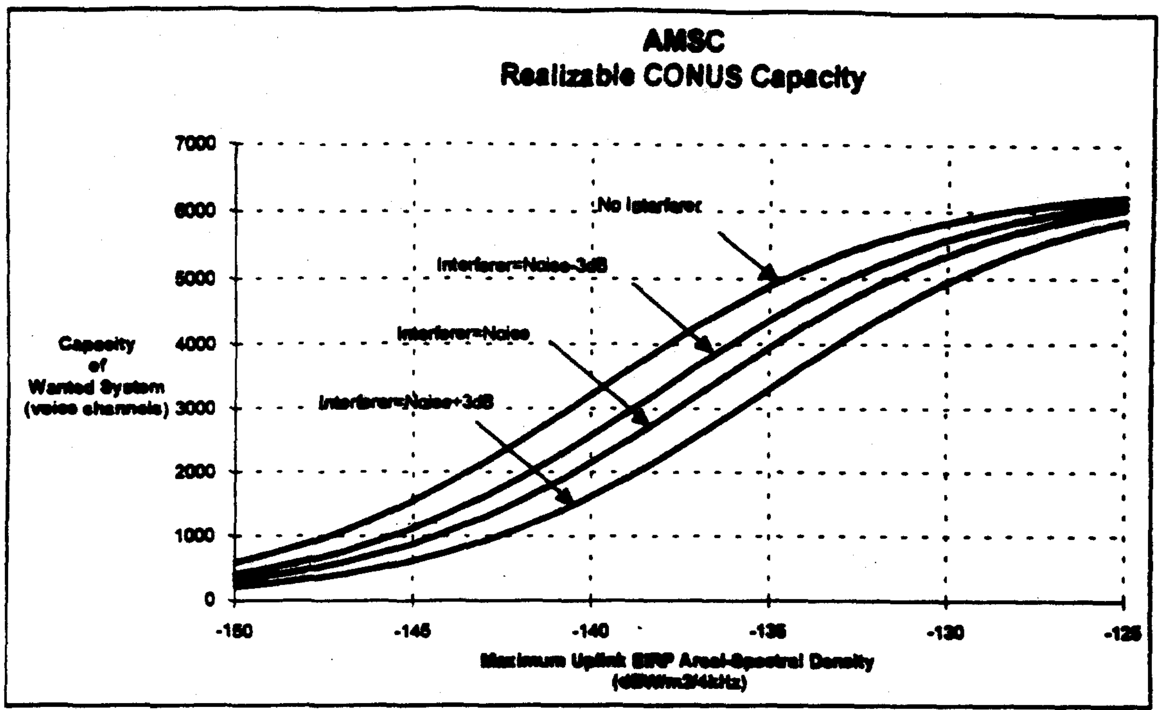

Figure 7 (Uplink, 16.5 MHz)

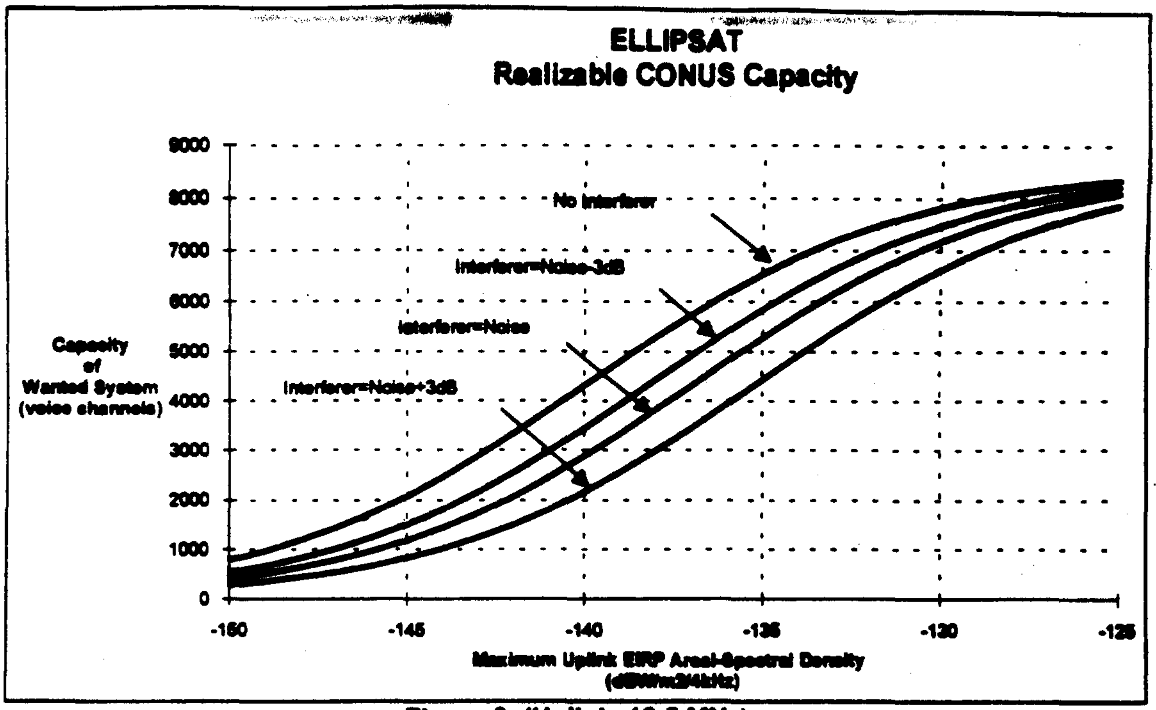

Figure 9 (Uplink, 16.5 MHz)

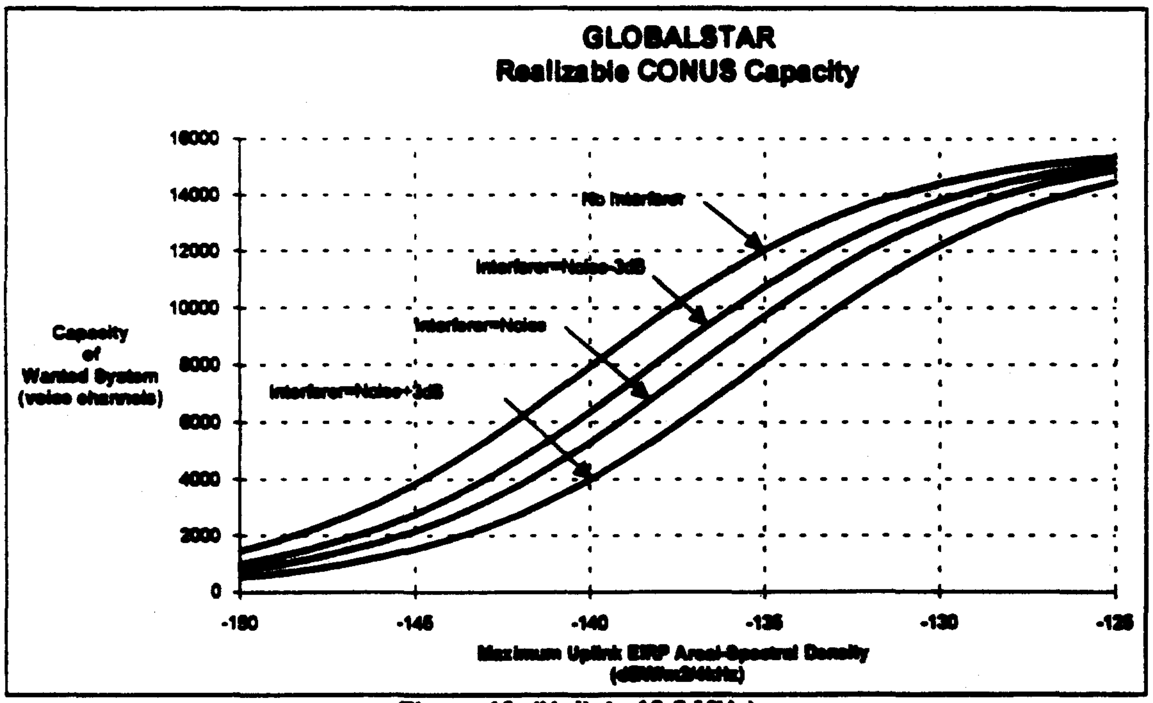

Figure 10 (Uplink, 16.5 MHz)

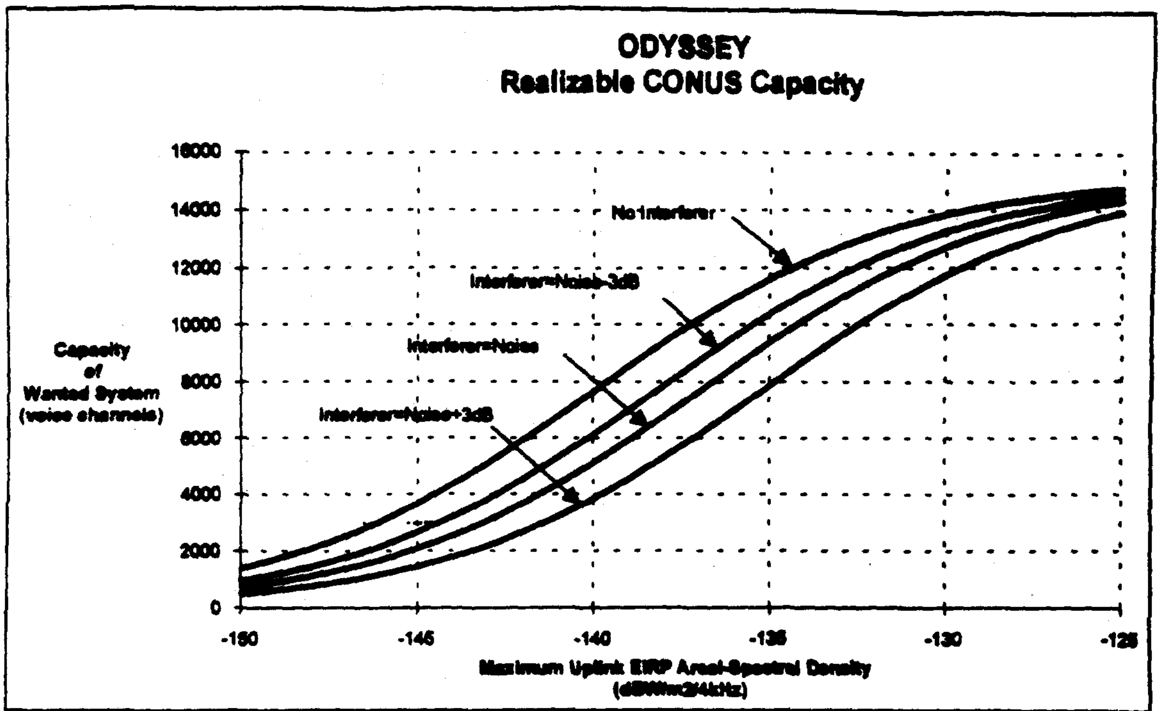

Figure 11 (Uplink, 16.5 MHz)

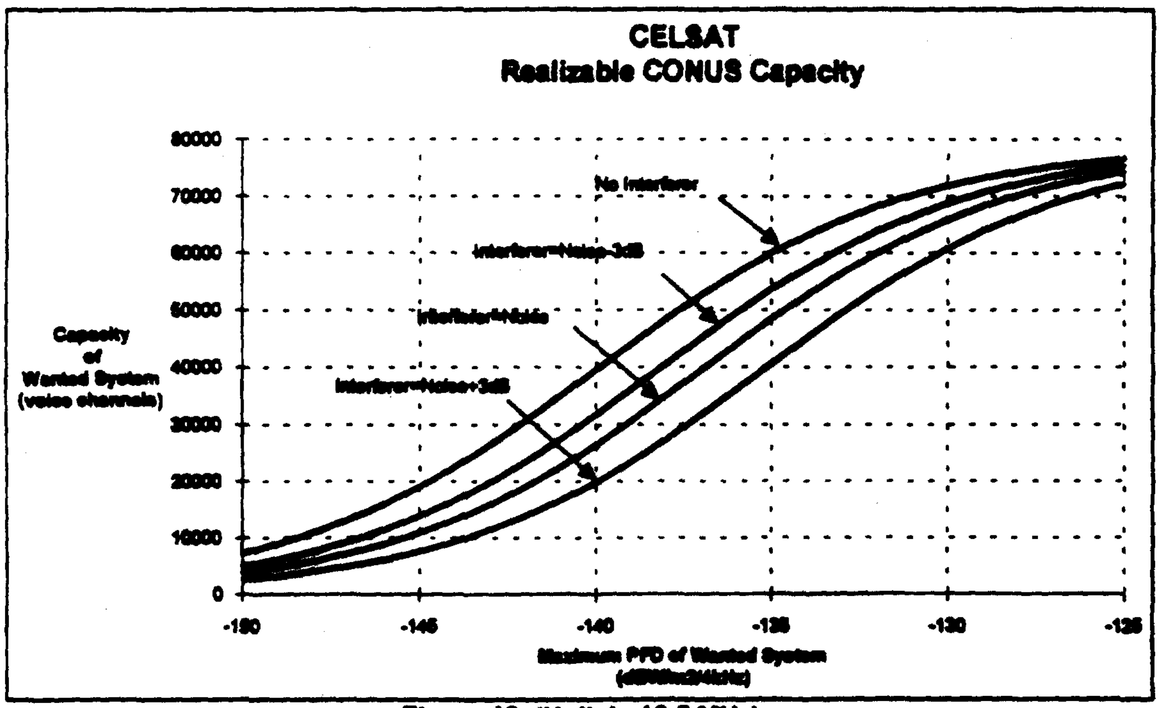

Figure 12 (Uplink, 16.5 MHz)

5.1.5.2 Collective Combined System Capacities (16.5 MHz Bandwidth)

This section addresses the collective CONUS uplink capacity achievable when the MSS systems analysed in section 5.1.5.1 are assumed to be operating simultaneously, co-frequency and co-coverage. In this section the full 16.5 MHz bandwidth is assumed to be available. No use of orthogonal CDMA is assumed on the uplink.

The achievable individual and collective uplink capacities when multiple CDMA systems are in operation will depend on the amount of uplink EIRP areal-spectral density used by each system. There are therefore numerous permutations of varying amounts of this resource to each system that can be analysed.

Table 6 gives eleven example scenarios (described above in section 5.1.3.2) when all systems are assumed to be operating co-polar, showing the maximum uplink EIRP areal-spectral density in use by each system, the corresponding realizable capacity of that system, and the aggregate CONUS capacity (the sum of all the systems).

Scenario - Uplink	AMSC	Constell'n	Ellipsat	Globalstar	Odyssey	Celsat	Total
Case 1: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0	-143.0	
Resulting Capacity (# ccts)	804	668	1076	1983	1910	9882	16323
Case 2: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0	-140.0	
Resulting Capacity (# ccts)	918	763	1228	2284	2180	11293	18666
Case 3: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0		
Resulting Capacity (# ccts)	919	764	1230	2287	2183	0	7383
Case 4: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0		
Resulting Capacity (# ccts)	1071	890	1433	2841	2644	0	8879
Case 5: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0			
Resulting Capacity (# ccts)	1285	1068	1720	3170	0	0	7244
Case 6: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0		-140.0		
Resulting Capacity (# ccts)	1285	1068	1720	0	3053	0	7126
Case 7: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	715	594	967	3620	3380	0	9177
Case 8: Max. EIRP (dBW/m2/4kHz)		-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	669	1077	3861	3815	0	9422
Case 9: Max. EIRP (dBW/m2/4kHz)			-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	1232	4529	4362	0	10122
Case 10: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	0	5287	5091	0	10378
Case 11: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0	-143.0	
Resulting Capacity (# ccts)	0	0	0	4529	4362	11323	20214

Table 6 (co-polar: available bandwidth = 16.5 MHz)

The capacities achievable when using orthogonal polarization transmissions to increase isolation between CDMA MSS systems are presented in the following two tables. This was discussed above in section 5.1.3.2.

Table 7 gives the same eleven example scenarios but with the use of orthogonal polarizations between some of the systems (Right Hand Circular (RHC) and Left Hand Circular (LHC)). AMSC, Ellipsat and Globalstar are assumed to use RHC polarization and Constellation, Odyssey and Celsat are assumed to use LHC polarization. An average polarization isolation of 6 dB between RHC and LHC is assumed in these results.

Scenario - Uplink	AMSC (RHC)	Constell'n (LHC)	Ellipsat (RHC)	Globalstar (RHC)	Odyssey (LHC)	Celsat (LHC)	Total
Case 1: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0	-143.0	
Resulting Capacity (# ccts)	1118	930	1497	2759	2867	13763	22726
Case 2: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0	-140.0	
Resulting Capacity (# ccts)	1352	1124	1810	3336	3211	18836	27466
Case 3: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0		
Resulting Capacity (# ccts)	1169	972	1566	2885	2779	0	9371
Case 4: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0		
Resulting Capacity (# ccts)	1427	1186	1911	3521	3391	0	11436
Case 5: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0			
Resulting Capacity (# ccts)	1511	1257	2024	3729	0	0	8521
Case 6: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0		-140.0		
Resulting Capacity (# ccts)	1835	1526	2457	0	4360	0	10178
Case 7: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	953	792	1276	4692	4519	0	12233
Case 8: Max. EIRP (dBW/m2/4kHz)		-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	931	1489	5511	5307	0	13247
Case 9: Max. EIRP (dBW/m2/4kHz)			-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	1867	5763	5550	0	12881
Case 10: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	0	7049	6788	0	13837
Case 11: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0	-143.0	
Resulting Capacity (# ccts)	0	0	0	6675	6428	16688	29791

Table 7 (cross-polar isolation = 6 dB; available bandwidth = 16.5 MHz)

Table 8 gives the results of the same eleven examples but with the average polarization isolation reduced to only 3 dB.

Scenario - Uplink	AMSC (RHC)	Constell'n (LHC)	Ellipsat (RHC)	Globalstar (RHC)	Odyssey (LHC)	Celsat (LHC)	Total
Case 1: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0	-143.0	
Resulting Capacity (# ccts)	989	822	1324	2440	2360	12173	[illegible]
Case 2: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0	-140.0	
Resulting Capacity (# ccts)	1167	970	1563	2880	2773	14366	[illegible]
Case 3: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-143.0	-143.0		
Resulting Capacity (# ccts)	1072	891	1435	2844	2547	0	[illegible]
Case 4: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0	-140.0		
Resulting Capacity (# ccts)	1284	1068	1719	3169	3052	0	[illegible]
Case 5: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0	-140.0			
Resulting Capacity (# ccts)	1427	1187	1911	3822	0	0	[illegible]
Case 6: Max. EIRP (dBW/m2/4kHz)	-140.0	-140.0	-140.0		-140.0		
Resulting Capacity (# ccts)	1606	1336	2150	0	3815	0	[illegible]
Case 7: Max. EIRP (dBW/m2/4kHz)	-143.0	-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	858	713	1148	4223	4067	0	[illegible]
Case 8: Max. EIRP (dBW/m2/4kHz)		-143.0	-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	823	1326	4874	4884	0	11717
Case 9: Max. EIRP (dBW/m2/4kHz)			-143.0	-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	1437	5283	5067	0	[illegible]
Case 10: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0		
Resulting Capacity (# ccts)	0	0	0	6343	6106	0	[illegible]
Case 11: Max. EIRP (dBW/m2/4kHz)				-140.0	-140.0	-143.0	
Resulting Capacity (# ccts)	0	0	0	5763	5650	14409	25722

Table 8 (cross-polar isolation = 3 dB; available bandwidth = 16.5 MHz)

5.1.5.3 Collective Combined System Capacities (10.5 MHz Bandwidth)

An analysis was also performed of the system capacities when only 10.5 MHz bandwidth is assumed to be available, due to inter-service sharing constraints in the band 1610-1616 MHz. As expected, these results show a reduction in the ratio of 10.5 MHz to 16.5 MHz, or a ratio of approximately 64%.

Annex 5.1: SYSTEM INVARIANT MSS UPLINK AND DOWNLINK SHARING CRITERIA

The Need for Sharing Criteria

This annex shows that the ground level Power Flux Spectral Density per system for the downlinks, and the Area Aggregate EIRP Spectral Density per system for the uplinks, both possess the fundamental properties necessary to allow them to act as the primary coordination interface parameters between CDMA MSS systems, irrespective of the individual systems' satellite altitude and gain.

Downlinks

For space-to-Earth downlinks, the PFD density criterion, ($W/m^2/Hz$ in basic units) is such a fundamental criterion. That it applies equitably, independent of satellite altitude and gain is self evident. A victim receiver doesn't care where the interference came from, only its signal strength or flux density. And all MSS systems suffer essentially equally from a given level of interference measured in terms of PFD. For near omnidirectional subscriber unit antennas, prescribing PFD is equivalent to prescribing an interference spectral density at the receiver input[1] which may be related directly to receiver thermal noise. It has been shown several times in these proceedings that the power efficiency (circuits per watt) and the spectral efficiency (circuits per MHz) of an MSS band sharing system, depend on the ratio, r, of total (including self-) interference spectral density to fundamental receiver noise spectral density. When that ratio is very small the bandwidth spectral efficiency is poor; when the ratio is large, power efficiency suffers as well as the general interference level to other services. A design optimum usually occurs about the knee of the curve where interference spectral density equals noise spectral density. For S-band and typical subscriber unit G/T of about -24 dB/K this occurs at a PFD of -139.2 $dBW/m^2/4kHz$. Thus even without PFD limits, the individual systems, in attempting to optimize their capacity and efficiency, end up with PFDs in a small range about -139. PFD is a fundamental and equitable sharing criterion for down-links. Four systems, each using a PFD limit of -139 $dBW/m^2/4kHz$, would each suffer a reduction of nominal non-shared capacity by a factor of about 2/5.

Uplinks

For the Earth-to-space links it may not be quite so obvious that the uplink EIRP areal-spectral density plays an exactly similar fundamental role. Interestingly, it also has the same fundamental units as PFD, $W/m^2/Hz$. This is analogous to the brightness of an extended optical source. Specifying the EIRP areal-spectral density determines the absolute available interference power spectral density, I_o, at the satellite receiver

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1 Power or power density levels at the receiver input referred to herein are in terms of "available power", that is available into a matched load.

input independent of satellite altitude or antenna gain or waveform details and dependent only on wavelength. This comes about as follows:

For a satellite antenna viewing the Earth, that is without significant sidebands off the Earth nor significant atmospheric absorption, the effective antenna noise is simply T_e, the effective temperature of the Earth with which the antenna is in radiative equilibrium. The available noise power spectral density, I_o, at the receiver input is then kT_e, W/Hz. If the satellite receiver has a good low noise amplifier, this then is the fundamental system noise limit which determines the minimum power for uplinks. Notice that it is independent of satellite altitude and antenna gain.

Now consider the interference. For the time being we approximate a uniform distribution of point emitters as an areal density of uniform brightness, ε, W/m²/Hz, like a uniformly bright extended optical source. The satellite antenna gathers in the total radiation from an area equal to its effective beam footprint on the Earth. By the definition of gain, the footprint subtends an effective solid angle of $4\pi/G$, and therefore, an area on the surface of the Earth, A_f, where:

$$A_f = 4\pi R^2 / G$$

where R is the Earth-to-satellite distance and G the satellite antenna gain. The total effective isotropic interference power spectral density, β, radiated from within the footprint is then:

$$\begin{aligned} \beta &= \varepsilon A_f \\ &= 4\pi R^2 \varepsilon / G \end{aligned}$$

Finally, the available interference power spectral density at the satellite receiver front end, I_s, is just this total radiated power, times the transmission loss including free space loss and antenna gain:

$$I_s = \beta G \lambda^2 / (4\pi R)^2$$

or

$$I_s = \varepsilon \lambda^2 / 4\pi$$

Thus the factor $G/4\pi R^2$ cancels out and the interference level at the receiver input is exactly independent of G and R.

Equating the interference to thermal radiation at temperature, T_e:

$$kT_e = \varepsilon \lambda^2 / 4\pi$$

This equation is familiar to radio astronomers as the Rayleigh-Jeans law for radiation from uniform extended radio noise sources. This is a remarkable and perhaps counter-intuitive result: The interference spectral density at an MSS satellite receiver front end, from a uniformly distributed source over the beamwidth of the satellite antenna, depends only on the effective isotropic radiated power areal-spectral density of the source and the wavelength of the radiation, and is independent of satellite antenna gain and altitude or distance from source to receiver. Similarly, the noise spectral density depends only on the effective noise temperature of the Earth in the field of view of the antenna.

Thus such a criterion ensures that all just complying systems operate at the same interference-to-noise ratio and at the same potential power and spectral efficiency, that is it treats all systems equitably, irrespective of altitude, whether LEO or GEO and irrespective of satellite antenna gain.

For a given frequency band, the satellite receiver front end interference spectral density, I_s, depends only on the EIRP areal-spectral density, ε, (W/m²/Hz) on the surface of the Earth. At 1610 MHz for example, the relation is simply:

$$I_s = 0.00276\,\varepsilon \quad \text{(W/Hz)}$$

It is useful as a point of reference to define a uniform source interference density or brightness, ε_{290}, that causes an interference level at an MSS satellite receiver input equal to the antenna noise due to the assumed 290 K Earth radiation. In other words:

$$0.00276\,\varepsilon_{290} = 290\,k$$

or, using k= 1.380E-23 W/Hz/K)

$$\varepsilon_{290} = -178.4 \text{ dBW/m}^2\text{/Hz},$$

again independent of satellite characteristics.

The significance of the interference is thus completely characterized for any MSS satellite at any altitude by the ratio $\varepsilon/\varepsilon_{290}$, independent of satellite altitude or gain.

Annex 5.2: ALTERNATIVE METHOD TO CALCULATE CDMA DOWNLINK SHARED CAPACITY

This annex describes an alternative way to calculate the capacity of an individual CDMA MSS system as a function of its PFD, and the PFD received from other interfering MSS systems.

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(see attached memo)

MEMORANDUM

TO: MSS NRMC IRWG-'
FROM: CELSAT
Jack Mallinckrodt
DATE: February 19, 1993 (Revised (*) 2/23/93)
SUBJECT: Data for Shared Capacity Calculations

CELSAT endorses and supports the TRW effort that has started to collect best current data to perform the shared capacity calculations under different scenarios. The requested data is understood to consist of the equivalent of pages 6 an 18 of Dr. Barnett's presentation, IRWG1-38.

However, we have some concerns about possible ambiguities, misinterpretations, or omissions of system peculiar relevent factors in these data. There is another way to the same result which is more directly connected to near bottom line system performance factors, may be less subject to such discrepancies, and in any case provides an important sanity check on the results. In addition, it supplies the operating point on the curve of page 6 which is the maximum *achievable* capacity, set by satellite power limits. This is the method set forth in Table 1 of the CELSAT submission, IRWG1-6.

The following three factors suffice to define the system capacity sharing characteristics. *It is suggested that these three data be added to the data requested by Dr. Barnett* (italics indicate flux densities and subscript $_{op}$ denotes design operating point):

1. The system maximum CONUS capacity, number of voice circuits, C_{op}.

2. The incident PFD, $I_{a,op}$, dBW/m^2/4kHz, at the worst case (max PFD) user geographic location in CONUS, when the system is operating at that maximum capacity. To the extent that individual link power is adaptively power controlled in response to a user's local fading environment, this represents an *average* over the distribution of power control.

3. The subscriber system G/T, dB/K where G is the antenna gain toward the satellite for the above worst case user and T the subscriber system noise temperature, deg K.

USAGE (* Revised 2/23/93)

The use of these terms is as follows:

1. C_{op} and $I_{o,op}$ together define the maximum operating point on the curve.

The rest of the curve is defined as follows.

2. First, convert all terms from dB to power ratios and densities to per Hz.
3. Define the system noise equivalent flux density, N_o from

$$N_o = N_o A_e \text{, or}$$
$$N_o \triangleq N_o / A_e$$

where A_e is the antenna capture area,

$$A_e \triangleq G \lambda^2 / (4 \pi).$$

4. Define the interference to noise density ratio, r:

$$r_{op} \triangleq I_{o,op} / N_o$$
$$= I_{o,op} (G/T) (\lambda^2 / 4\pi k).$$

5. The "Maximum" (self-noise limited, or theoretical asymptotic) capacity is then

$$C_{max} = C_{op} ((1+r_{op})/r_{op})$$

6. Similarly, for other than operating point PFD, define the interference to noise density ratio:

$$r(I_o) \triangleq I_o (G/T) (\lambda^2 / 4\pi k)$$

Then the rest of the curve of system non-shared capacity as a function of its allowable, or allocated maximum PFD is

* $$C(I_o) = C_{op} * [r(I_o)/r_{op}] \; [(1 + r_{op})/(1 + r(I_o))]$$
* $$= C_{max} * r(I_o) / [1 + r(I_o)]$$

provided $I_o <= I_{o,op}$.

The latter limit reflects the design power limitations of the actual system.

6. In the presence of a total interference flux density $I_{o,sum} >= I_o$ a system operating with an allocated PFD I_o has a reduced capacity

* $$C(I_o, I_{o,sum}) = C(I_o) \, [1 + r(I_o)] \, / \, [1 + r(I_{o,sum})]$$

The aggregate capacity of several systems sharing in this total PFD environment is given simply by the addition of these terms for each system.

Annex 5.3: METHOD FOR CALCULATING THE AVERAGE UPLINK PROPAGATION MARGIN

This annex describes a simple model which can be used to determine the average uplink propagation margin, based upon a simple two-state propagation model.

Assuming that the two-state model is defined as follows:

β is the percentage of users that are shadowed.
$(1-\beta)$ is the percentage of users that are not shadowed.
Shadowed users experience a propagation impairment of F (linear).
Unshadowed users experience no propagation impairment.

Then the average uplink propagation margin in dB, G_u, is given by the following equation:

$$G_u = 10\log((1-\beta).\beta.F + (1-\beta).(1-\beta) + \beta.((1-\beta) + \beta.F)/F)$$

As an example, if $\beta = 20\%$, and F = 4 times (or 6 dB), then the above equation results in:

$$G_u = 1.32 \text{ dB}$$

In the case of a multi-state propagation model, a more complex analysis is required to arrive at the average uplink propagation margin, but the same principles can be applied.

5.2. CDMA vs. FDMA/TDMA.

5.2.0. Introduction. This section discusses the potential for sharing among the proposed TDMA and CDMA systems. One approach to CDMA/TDMA sharing is outlined here.

Motorola's proposed Iridium system, which uses TDMA access modulation, cannot viably operate as currently designed on a co-frequency, co-coverage basis with the proposed CDMA systems. (See Annex 5.2.3.) Motorola's views why the concept described here is not a viable approach are presented in Section 5.2.7.

5.2.1. Full Band/Polarization Interference Sharing. Full Band Interference Sharing for systems with different technologies (CDMA, TDMA, LEO & GSO), in co-frequency/co-coverage environments, is accomplished on one basic principle, i.e., to reduce interference generated by other systems and to allocate an appropriate amount of noise budget for interference.

One way to separate the interference signal from the wanted signal is to use pseudo-random coding, which is called spread spectrum CDMA in general. Full-band interference sharing among CDMA systems is covered in Section 5.1. A CDMA/TDMA sharing scheme is described in this section as presented in IWG1-73 (by Ming Louie of LQSS). It includes an analysis of achievable capacity for various systems and operating technical criteria.

5.2.2. Description of the CDMA/TDMA Scheme. The basic elements of this plan are as follows:

(1) All qualified applicants would be authorized to construct systems that can operate over both bands in their entirety (i.e. 16.5 MHz in L-band for the Earth-to-space link and 16.5 MHz in S-band for the space-to-Earth link), or as much thereof as they have requested in their applications.

(2) TDMA operation would be permitted in the top 2.75 MHz in both bands (i.e. from 1623.75-1626.5 MHz and from 2497.25-2500 MHz) with right hand circular polarization (RHCP).

(3) CDMA operation would be permitted with left hand

mobile terminal antennas and 20 dB cross-polarization isolation with their satellite antennas to minimize interference into systems in the opposite polarization.

(5) Sharing among CDMA systems would be determined by the CDMA Interference Sharing Criteria described in Sections 2, 3 and 5.1. The frequency and polarization plan of this sharing scheme is shown in Figure 5.2.1. The plan is further described in IWG1-73.

5.2.3. Sharing Analysis. The basic objective in any communications link design is to achieve a certain Eb/No for certain kind of service which requires a certain bit error rate (BER). The link design for the MSS is no exception. In CDMA/TDMA sharing, the No may be described as:

$$No = Nt + Is + Io$$

where

No: total noise density

Nt: thermal noise

Is: noise density caused by self interference, e.g. from adjacent beams

Io: noise density caused by interference from other systems sharing the same frequency

When a TDMA system operates at one polarization and CDMA systems operate at the opposite polarization, polarization isolation would reduce the amount of interference from one system into the other system.

In the MSS link design, the Eb (signal energy per bit) is another important factor. Eb is decided by EIRPs and receive antenna gains of mobile terminals and satellites. Eb is thus limited by the transmitted power of the mobile terminal and of the satellite. Both power of the mobile terminal and power of the satellite have great impact on the system cost. Thus optimizing the antenna gains of the mobile terminal and the satellite would become a major avenue to optimizing the whole system.

However, there is another factor in determining the achievable Eb, i.e. the degradation due to shadowing. When the direct line-of-sight path between the satellite and the mobile

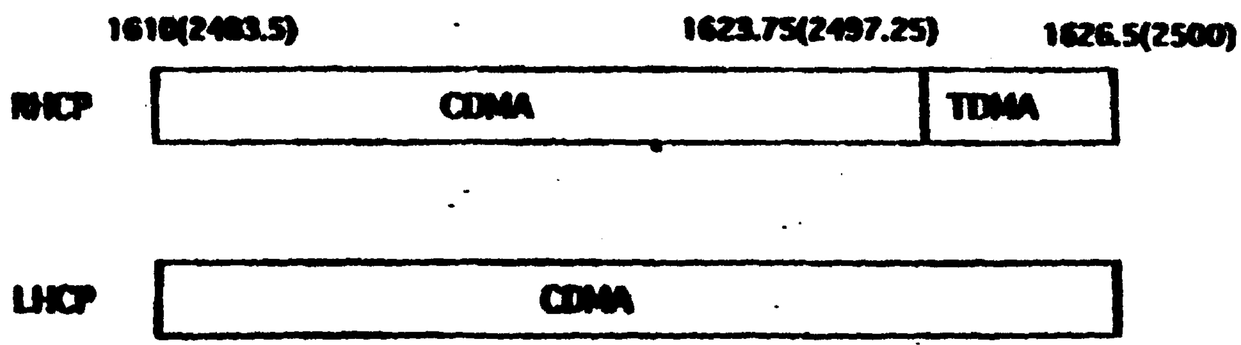

Figure 5.2.1 Frequency Plan with One TDMA System and Multiple CDMA Systems

terminal is shadowed by an obstacle, e.g. a tree, the wanted signal would suffer degradation. There are two approaches to overcome the degradation caused by shadowing: (1) to transmit more power from the mobile terminal and from the satellite to overcome shadowing, i.e. fade margin; (2) to use another transmission path that is not shadowed nor blocked, i.e. path diversity. Using the fade margin alone would require that both the satellite power amplifier and the mobile terminal amplifier be able to transmit very high power when shadowing occurs; this would require that both amplifiers be able to operate over very large dynamic range (i.e. from very low power to very high power). The requirement of large dynamic range, especially at the low power range, would make the system vulnerable to other noises, such as interference from other systems sharing the same frequency. Operating the system at high power range would generate more interference into other systems sharing the same frequency. Thus, using large fade margin alone to overcome shadowing would reduce the feasibility of multiple systems sharing the same frequency. Even with large power margin, it may not be sufficient to overcome blockages, deep fades and multipath fades.

Using path diversity to overcome shadowing would require multiple satellite coverage and innovative signal processing techniques, such as rake receiver and coherent combining. Using path diversity alone may not be sufficient to overcome the shadowing fading.

Therefore, a combination of fade margin, power control and path diversity may allow MSS systems to have sufficient fade margin to overcome shadowing while maintaining high system availability. It also makes it easier for multiple systems to share the same frequency.

The basic principle to achieve CDMA/TDMA sharing is to achieve balance among Eb (wanted signal power density), Nt (thermal noise density) and Io (interference power density). An example to achieve CDMA/TDMA sharing has been shown in Document IWG-1-73. According to the above analysis:

(1) Full band, co-frequency, co-coverage CDMA/TDMA sharing is feasible;

(2) Achieves capacity of:
3640 voice circuits for a TDMA system, and
10,000 to 15,000 voice circuits for multiple CDMA systems

(3) Inter-system interference can be limited with 6 to 8 dB cross-polarization isolation of the mobile terminal antenna.

This is one of the scenarios for both CDMA and TDMA systems to share the same spectrum. Further optimization would enhance the sharing feasibility and improve the utilization efficiency of the L- and S- MSS spectral bands.

5.2.4. <u>System Adjustments to Optimize Frequency Sharing</u>. Both TDMA and CDMA systems would have to make adjustments to make CDMA/TDMA sharing feasible.

For the TDMA system:

(1) Operate in L- and S-bands; no bi-directional operation is permitted in order to eliminate the potential for interference from the secondary downlink into the primary uplink of other MSS systems and make international frequency coordination easier with other MSS/CDMA systems;

(2) Reduce TDMA data rate to reduce required power for the TDMA carrier, e.g. from 50 Kbps (TDD) to 20 Kbps (FDD);

(3) Improve mobile terminal antenna performance, e.g. 3 dB gain and 6-8 dB cross-polarization isolation; and

(4) Optimize antenna design to balance thermal noise and interference noise

For CDMA systems:

(1) Improve mobile terminal antenna performance, e.g. 3 dB gain and 6-8 dB cross-polarization isolation;

(2) Accept more interference from TDMA systems operating at higher PFD, thus reducing CDMA capacity of some systems;

(3) Optimize antenna design to balance thermal noise, interference noise from other systems (both TDMA and CDMA); and

(4) Some CDMA systems may have to change their channelization plan to accommodate non-homogeneous systems.