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통계적 채널 모델을 이용한 CDMA 이동위성통신시스템의 용량계산 기법

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CDMA Capacity Estimation Technique in Mobile Satellite System Using a Statistical Channel Model

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요 약

본 논문에서는 CDMA 방식을 사용하는 이동위성통신시스템에서의 실질적인 용량 계산 방식에 대하여 기술하였다. 비정지 궤도에서 운용되는 시스템에서 시스템의 특성을 가장 현실적으로 반영할 수 있는 용량 계산 기법에 대하여 살펴보았으며, 페이딩 환경에 따른 사용자의 간섭과 같은 이동위성통신 환경에 대한 효과를 고려하기 위하여 통계적인 채널 모델[1]을 사용하였다. 임의의 한 저궤도 이동위성통신시스템을 사용하여 우리 나라 지역에서의 상향 링크에서의 용량을 계산한 예를 제시하였는데, 위성 다이버시티 방식의 채택 유무에 따른 결과를 비교하여 다이버시티 방식의 채택으로 인한 이득을 분석할 수 있도록 하였다.

ABSTRACT

In this paper, an effective estimation technique on the CDMA capacity in mobile satellite system (MSS) is described. The normalized capacity estimation technique which can incorporate the characteristics of the system operating in N-GSO (Non-geostationary satellite orbit) is considered. In order to include mobile satellite communication characteristics such as faded user interference, a statistical channel model[1] is used. We present an example of up-link capacity estimation results by using a MSS in low earth orbit. Comparison of the estimation results by diversity scheme provided in this paper would make it possible to analyze the advantage of adopting a diversity scheme.

I. Introduction

As a consequence of the growing interest of the CDMA in mobile satellite systems, the feasibility often with the capacity issue has been discussed in several papers [2]-[6]. Due to the characteristics of mobile satellite channel, the gain of adopting CDMA system in mobile satellite system is usually less than in terrestrial cellular system. Therefore the effectiveness of CDMA technique over the satellite channel should be evaluated by accounting the characteristics of MSS. The potential problem of using CDMA in MSS can be summarized as follows[6].

- Due to the longer round trip delay, only inaccuracy open-loop power control and imperfect interleaving can be used.
- Due to the smaller delay spread (usually less than 100ns), the coherence bandwidth of the satellite channel should be at least 10MHz in order to take advantage of multipath diversity using RAKE receivers.
- The frequency reuse will cause multiple access

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interference, so, the coexist of several systems will cause the capacity reduction of individual system

- WARC-92 has set $-142(\text{dBW/m}^2/4\text{kHz})$ as the Coordination Trigger Level(CTL) of MSS. For MSS, the CTL means the upper limit of user's receiving power flux density (PFD), i.e. CDMA system works at a power limited condition, it also causes the reduction of capacity.

Monsen[3] proposed an estimation method for CDMA beam capacity by considering the problems stated above comparatively in detail. In his work, however, only a specific average capacity value has been considered in a given environment instead of considering the variation of fading statistics with satellite geometry. Faded user interference effect was included by considering the amount of interference from the users in the shadowing conditions to the users in the clear view to the satellite. This requires shadowing probability value which is very difficult to extract, since the definition of shadowing cannnot be unique. In [3], a specific results presented by Lutz[11] which is a part of the measured values in city and highway environment were used. This method, thus, can only be applied to the specific conditions provided in [11].

In this paper, we propose a new estimation technique which can be applied to any environment which can be expressed by a statistical channel model. Since the statistical fading model was developed in ETRI (Electronics and Telecommunications Research Institute) [12] by using the Corazza model, and this model can express mobile satellite propagation channels under open, rural, and urban environments and thus this model enables the proposed technique to be applied to any situation.

In the proposed technique, the link availability is firstly found with a given allowable system power margin, and the effect of the faded user interference is considered for the available links. The link availability and the faded user interference effect are estimated as the movement of the satellites in a given orbit constellation. These values will be changed by the elevation angles and terrain. We present estimated capacity resulting from the link availability and interference with the variation of elevation angles in a given environment.

A general capacity estimation method of the single cell CDMA system and a practical formula suitable for estimating beam capacity of the CDMA in MSS are provided in Chapter II. The detailed expression of the capacity estimation formula is given and also the concept of each parameter used in the formula is provided. In Chapter III, some estimation results are given with the analysis of them, and finally in Chapter IV conclusions are drawn with a suggestion of further works.

II. Capacity of the CDMA System

1. CDMA capacity in terms of number of users

In a single cell environment, the capacity of a CDMA system in terms of number of users in a cell can be express as [7],

$$N_u - 1 = \frac{PG}{(E_b/N_o)_{req}} \tag{1}$$

where, N_u is number of available channels to users in a cell and PG is the processing gain of the CDMA system which is the ratio of transmitting bandwidth to transmission bit rate. The ratio $(E_b/N_o)_{req}$ is defined as the ratio of energy per bit to the noise power spectral density that is required by the particular modulation and coding scheme utilized.

Since the system cannot be operated in a single cell environment we need to impose the effect of multi-cell system environment with other effects which can increase or decrease the capacity. For example, in the case of terrestrial cellular system with voice activation scheme and cell site antenna (typical 120° sector antennas), the cell capacity can be expressed as

$$N_u \simeq \frac{PG}{(E_b/N_o)_{req}} \frac{1}{D} FG_a \tag{2}$$

where, D is the voice utilization factor which accounts for the reduction in interference energy due to the voice activation scheme, G_a is the sectorizarion gain, and F is the frequency reuse efficiency.

2. CDMA Capacity in MSS Using Low Earth Orbit

Similar to the capacity equations in the terrestrial cellular system, the capacity of the CDMA system for MSS can be expressed as

$$N_u = \frac{PG}{(E_b/N_o)_{req}} \frac{1}{F_{MAI}} \quad (3)$$

As in the terrestrial CDMA system, there are several factor which incorporates the characteristics of mobile satellite system. The F_{MAI} in eq. (3) is defined as the Multiple Access Interference (MAI) factor, and represents the characteristics of MSS and the effects of other performance improvement techniques. That is

$$F_{MAI} = \frac{v_u f_m r_c}{L_a f_r} \quad (4)$$

where v_u is the voice utilization factor, f_m is the fade margin factor, L_a is the link availability factor, f_r is the frequency reuse factor, and r_c is the range compensation factor. The definition and estimation procedure of each factor will be described.

2.1 Voice Utilization Factor (v_u)

This factor, having values in the range between 0 and 1, accounts for the reduction in interference energy due to the voice activation technique. In CDMA systems, the interference levels can be reduced by reducing the voice processing date rate during quiet voice periods. Reducing the data rate but maintaining a constant E_b value leads to reducing the transmit power, and produces a proportional reduction in the interference power. In an ensemble of statistically independent users the voice utilization factor is then

$$v_u = f_v[v_a + (1 - v_a) r_f] + 1 - f_v \quad (5)$$

The descriptions and typical values of the variables in eq. (5) are presented in Table 1.

Table 1. Typical values of voice utilization factor [3]

variables	description	typical values
f_v	fraction of voice users	0.8
v_a	probability that voice user is active (voice activity factor)	0.35
r_f	date rate reduction factor	0.25
v_u	voice utilization factor	0.6

2.2 Link Availability Factor (L_a)

This factor, having values in the range between 0 and 1, accounts for the reduction in the number of available channels because of the signal fading and limited amount of system power margin. In other words, L_a is the fraction of users who can be provided an acceptable performance of service and 1-L_a is the faction of users who can not be provided acceptable performance of service with the maximum amount of power margin. Later, statistical estimation results of L_a with and without satellite diversity will be presented in detail.

2.3 Fade margin factor (f_m)

This factor, having values of less than or equal to 1, accounts for the additional interference energy due to the increase in other user power to combat fading when the link is available. The increase in MAI due to power augmentation by some of the users to overcome fading depends on the percentage of the link availability due to space and time geometry of the satellite cell.

Because of the fading process and inability to track the fading perfectly in a satellite cellular application, these users require additional power to provide acceptable performance under fading as opposed to non-fading condition. Let $d_c>1$ represents this degradation compensation factor. The faded user power must also be adjusted for the resulting attenuation which is defined as the attenuation factor, denoting $a_c \geq 1$. The value of d_c and a_c vary from user to user depending on the geometry. In this paper, same to the L_a, a_c *is* estimated by simulating the motion of a particular satellite orbit constellation in a location in Korea with the rural tree shadowed environment. In the case of d_c, a single value is used which is for compensating the performance difference of a specific modulation and coding scheme in AWGN(Additive White Gaussian Noise) and in Rayleigh fading channel.

In the shadowed path between the transmitter and the receiver, there are two fading possibilities: (1) slow fading, e.g., stationary or slow moving (<2km/h) users with shadowing, where the adaptive power control can track the fading variations, and (2) fast fading, e.g., moving vehicles with shadowing, where the adaptive power control tracks the mean received power and not the actual fades. In the former case the interference factor is a_c, i.e. attenuation compensation only. In the latter case the interference factor is $a_c d_c$, i.e. both attenuation and degradation compensation. We denote s_s and s_f are the fraction of the users in slow and fast fading conditions.

To calculate the fade margin, we need to consider the amount of power increase for the users whose link is available with maximum allowable power margin. For the down-link the fraction of users who require a fractional power increase of either $a_c d_c$ is s_f and a_c is s_s respectively The down-link fade margin MAI factor in a single satellite system is then

$$f_m = s_f a_c d_c + s_s a_c \quad \text{on down-link} \tag{6}$$

For the up-link, the interference from a shadowed user is independent of the attenuation because the attenuation compensation by the adaptive power control system and the attenuation in the medium cancel each other. The up-link fade margin factor is

$$f_m = s_f d_c + s_s \quad \text{on up-link} \tag{7}$$

As in the case of the L_a, f_m is also statistically estimated.

2.4 Frequency Reuse Factor (f_r)

This factor, having values greater than or equal to 0, accounts for the additional interference energy due to users in adjacent beams and the potential interference decrease when ideal orthogonality is achieved within the beam. The frequency reuse factor of the CDMA systems can be calculated for up-link as follows

$$f_r = \frac{1}{1+N_1A_1+N_2A_2} \tag{8}$$

The descriptions and typical values of the variables in eq. (8) are presented in Table 2.

Table 2. Typical values of frequency reuse factor

variables	description	typical values
N_1	number of adjacent cells	6
N_2	number of next to adjacent cells	12
A_1, A_2	coupling values for N_1 and N_2 cells respectively	−10.2, −29 (dB)
f_r	frequency reuse factor with asynchronous PN seq.(up-link)	1.566 or 1.9dB

The typical values in Table 2 were found by using a square law path loss dependence for frequency reuse in satellite systems.

2.5 Range compensation factor (r_c)

This factor, having values of greater than or equal to 1, accounts for the additional interference energy when antenna gain and range can not be perfectly compensated over the beam area. That is, additional interference in a multiple system application results from the inability to equalize the antenna gain to path loss ratio over the satellite cell. The effects, however, will not be included in this paper since we will only consider a single satellite system case.

III. Estimation Results

The up-link capacity of CDMA in a MSS has been estimated by using the orbit constellation of the Globalstar system of which space segment is comprised of 48 LEO satellites[9]. The satellites are organized in a 48/8/1 Walker constellation (8 satellite planes with 6 satellites per plane), with 1414km altitude and 52 degrees inclination. Orbital period is 114 minutes.

In the capacity estimation procedure, first of all, we need to know required E_b/N_o value which is dependent on the particular modulation and coding scheme employed. In this paper, the transmission scheme of a terrestrial standard (IS-95) for cellular communications is used. In Table 3, modulation and coding schemes and required E_b/N_o value is presented.

Table 3. Estimation of the required E_b/N_o value for up-link

modulation	64-FSK	
coding	convolutional code($r=1/3$, $K=9$)	
theoretical $(E_b/N_o)_{req}$ (dB)	3.9	
Implementation loss(dB)	0.5	
power control margin(dB)	1.0	
pilot power(dB)	0.0	
combining loss(dB)	0.0	1.0 (with diversity scheme)
effective $(E_b/N_o)_{req}$(dB)	5.4	6.4(with diversity scheme)

The implementation loss in Table 3 is the loss for the modem used in the system, and 0.5dB is a typical value for the digital modems. As mentioned earlier, the adaptive power control tracks a slow varying mean value of attenuation in a satellite system instead of the actual attenuation value because of the longer round trip delay. Because of this imperfect power control, extra margin must be provided at the demodulator. A value of 1dB is used here, which is the same value to the one used in the Globalstar system.

In a system with path diversity, the signals can be coherently combined with negligible loss in the down-link direction with the aid of two down-link pilots. For the up-link, square law combining is optimum under the worst case Rayleigh-fading conditions that may occur in a shadowed environment. Usually, there is about a 0.8dB combining loss when equal strength signals. When the signals are unequal, this loss is somewhat larger. A value of 1dB is used since the signal strength is not usually the same.

Evaluation of the MAI factor is also required to estimate the capacity. Among the factors which consists of MAI factor, the link availability factor(L_a) and the fade margin factor (f_m) are the factors of which values are varied as the satellite moves. The propagation model which describes the fading conditions of MSS[1] was used, and as an example of the tree-shadowed rural environment was employed.

By simulating the motion of the satellite constellation in a tree-shadowed rural environment in Korea located at 127° E and 36.5° N, the statistical data of the signal propagation has been collected for every possible elevation angle. That is, all necessary parameters for evaluating F_{MAI}, such as the link availability, mean value of attenuation when the link is available, and etc., have been statistically produced with the variation of elevation angles. In order to estimate the average capacity, the percentage of time of elevation angles are also investigated during 350 orbital periods which can cover the whole satellite motions.

1. Fading Statistics and Capacity of Systems without Satellite Diversity

In the system without satellite diversity, we assume that a user communicates with the satellite which provides the highest elevation angle to the user. In Figure 1, the time percentage are taken by collecting the best elevation angle values at the given geographical point. When the system power margin values are provided, the variations of the link availability with elevation angles are represented in Figure 2. A larger link availability can be achieved with a larger power margin. In this paper, we consider 4 different values of power margin, 10, 15, 18 and 20 dB. Figure 2 indicates that, for example, in order to achieve 90% of link availability with 10 dB link margin the minimum elevation angle required is about 65°. Since the elevation angle changes as the satellite moves, average values of link availability considering percentage of time at each elevation angle should be considered for the system design process.

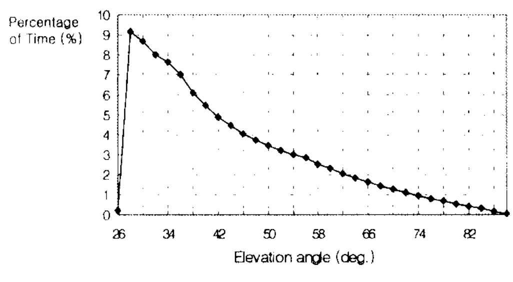

Figure 1. Percentage of time at each elevation angle (the best elevation angle)

Figure 3 and Figure 4 show the variation of the normalized capacity with elevation angles. Figure 3 shows the capacity curves which were drawn by estimation results with a given value of power margin, 10dB, and with various values of S_s (fraction of users in slow fading condition). As mentioned earlier, the fade margin factor is dependent on the conditions of fading environment (i.e., slow or fast fading). As shown in Figure 3, if the faction of the users in the fast fading conditions increases, the capacity decreases. This is because a larger compensation power is required for users in fast fading conditions.

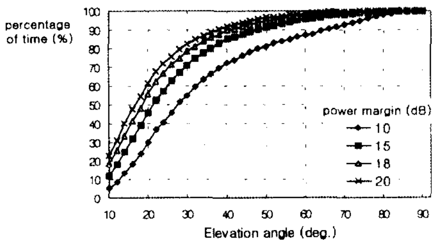

Figure 2. Variation of link availability with elevation angle and given link power margin in tree-shadowed rural environment

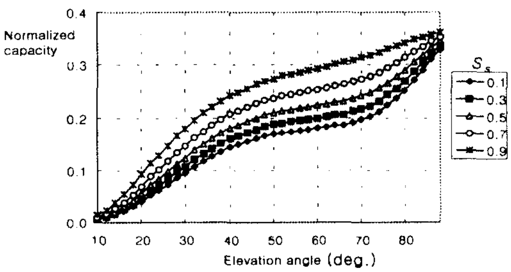

Figure 3. Capacity variation according to the variation of the fraction of users in slow fading conditions (S_s)

On the other hand, Figure 4 shows the capacity curves which were drawn by estimation results with a fixed value of $Ss = 0.7$, and several different values of system power margin. As Figure 4 indicates, the capacity increases with power margin in lower elevation angles. However, in higher elevation angles, the capacity is independent of power margin values. This is because larger power margin means higher interference, and capacity is decreased.

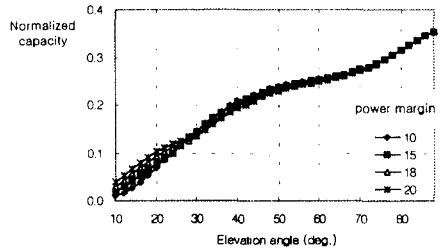

Figure 4. Capacity variation according to the variation of the system power margin

2. Fading Statistics and Capacity of Satellite Diversity System

If a system employs the dual path satellite diversity schemes, one should consider the time percentage of both satellites' elevation angle communicating at the same time. Figure 5 represents the probability of the second satellites' elevation angle providing the first satellites' elevation angles are given such, and Figure 6 is the 2 dimensional plot showing the joint probability of both elevation angles in the dual path diversity system at the location of 127° E and 36.5° N.

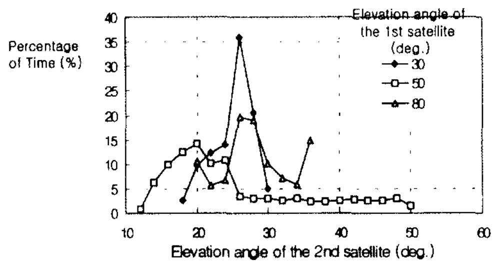

Figure 5. Time percentage of the second elevation angle at a given elevation angle of the first satellite in the dual path diversity system

Using statistical data of the fading characteristics of the given orbit constellation at the given point, the link availability factor and the fade margin factor has been estimated in the dual path diversity system. Figure 7 and Figure 8 show the link availability and capacity plot with variation of both elevation angles of two satellites.

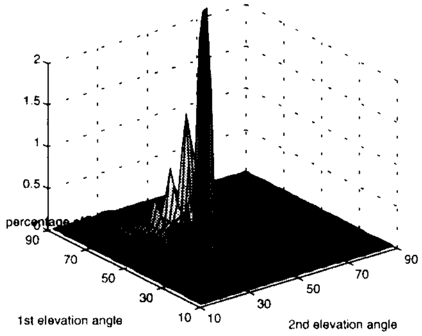

Figure 6. Percentage of time of elevation angle in the dual path satellite diversity system

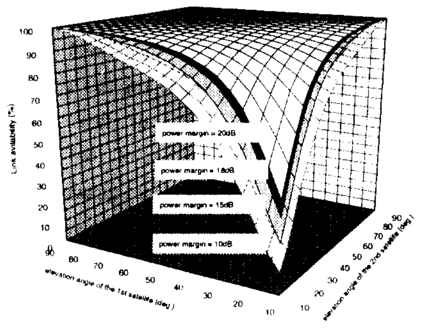

Figure 7. Variation of link availability in the dual path satellite diversity system

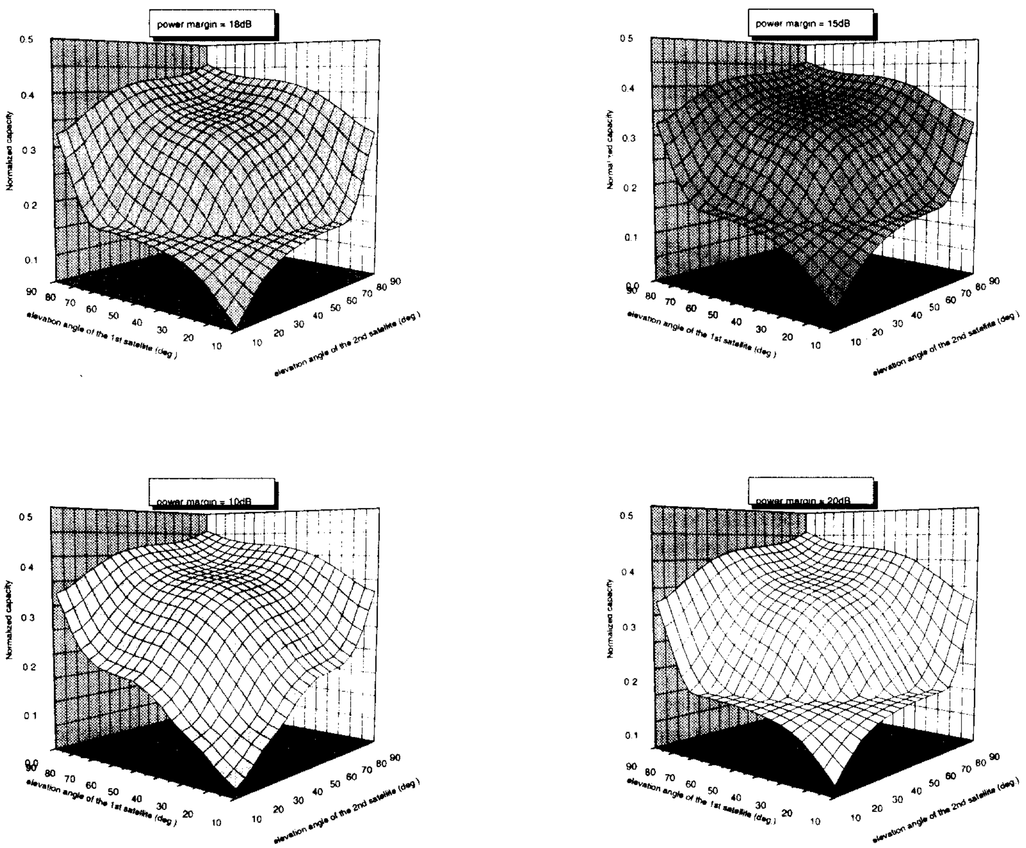

Figure 8. Variation of normalized capacity in the dual path satellite diversity system

3. Estimation of Average Capacity

Table 3. Average capacity accounting the percentage of time of elevation angles

Power margin(dB)	without diversity	with diversity	with diversity (effective)
10	0.21	0.21	0.11
15	0.20	0.41	0.20
18	0.20	0.60	0.30
20	0.20	0.80	0.40

Table 3 shows the average normalized capacity which was estimated by considering time percentage of elevation angles at 127° E and 36.5° N. The effective capacity with diversity scheme is estimated by acunting that a user occupies two channels in differ-t satellites at the same time. That is the effective capacity is the half of the estimated capacity in dual path diversity system. Although the effective capacity in the diversity system is smaller than the one in non-diversity system, the capacity enhancement will be much larger in the aspect of overall system capacity. This is because the traffic distribution is non-uniform, and in most of the cases a user in highly populated area can occupy another channel in the satellite which have a very low traffic load.

IV. Conclusions and Further Works

In this paper, the capacity estimation technique of the CDMA scheme in MSS was proposed. It is focused on the variation of link availability and fading margin values according to the elevation angles at a given area, and their effect on the capacity values. By averaging the capacity values with percentage of time of the elevation angles in the area, average capacity values and effective capacity in the diversity system have been found. The estimation results with fading statistics in the rural area showed that the beam capacity can be increased by adopting the dual path diversity scheme. The proposed technique is thus turned out to be very suitable to estimate CDMA system capacity operating in low earth orbit.

In order to estimate the overall system capacity, the fading statistics of various environment and the distribution of each environment in whole service area should be investigated. Traffic distribution of the service area and resource allocation scheme of the considering system are also important factors to determine the overall system capacity.

References

1. Corazza, G. E., and Vatalaro, F., "Statistical Model for Land Mobile Satellite Channels and Its Application to Nongeostationary Orbit Systems", IEEE Transactions on Vehicular Technology, Vol. 43, No. 3, pp. 738-742, 1994.
2. Gilhousen, K. S., Jacobs, I. M., Padovani, R., and Weaver, Jr., L. A., "Increased Capacity Using CDMA for Mobile Satellite Communication", IEEE Journal on Selected Areas in Communications, Vol. 8, No. 4, pp. 503-514, 1990.
3. Monsen, P., "Multiple-Access Capacity in Mobile User Satellite Systems", IEEE Journal on Selected Areas in Communications, Vol. 13, No. 2, pp. 222-231, 1995.
4. Vojcic., B., R., Milstein, L. B., and Pickholtz, R. L., "Total Capacity in a Shared CDMA LEOS Environment", IEEE Journal on Selected Areas in Communications, Vol. 13, No. 2, pp. 232-244, 1995.
5. Johannsen, K. G., "Code Division Multiple Access Channel Capacity in Mobile Satellite Communication", IEEE Transactions on Vehicular Technology, Vol. 39, No. 1, pp. 17-26, 1990.
6. Zhang, G., "The Capacity Calculation of CDMA Mobile Satellite Communication System", International Conference on Communication Technology, pp. 55-59, Beijing, China, 5-7, May 1996.
7. Gilhousen, K. S., Jacobs, and et al., "On the Capacity of a Cellular CDMA System", IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, pp. 303-312, 1991.
8. Rappaport, T. S. and Milstein, L. B., "Effects of Radio Propagation Loss on DS-CDMA Cellular Frequency Reuse Efficiency for the Reverse Channel", IEEE Transactions on Vehicular Technology, Vol. 41, No. 3, pp. 231-242, 1992.

9. Schindall, J., "Concept and Implementation of the Globalstar Mobile Satellite system", Proceedings of the 4th International Mobile Satellite Conference 1995, Ottawa, Canada, pp. A-11-16.
10. Viterbi, A.J., Viterbi, A. M., and Zehavi, E., "Performance of Power controlled wideband terrestrial digital communication", IEEE Transactions on Communications, Vol. 41, No. 4, pp. 559-569, 1993.
11. Lutz, E., Cygan, D., Dippold, M.., Dolainsky, F., Papke, W., "The Land Mobile Satellite Communication Channel-Recording, Statistics, and Channel Model", IEEE Transactions on Vehicular Technology, Vol. VT-40, No. 2, May 1991, pp. 375-38611.
12. ETRI, "Research and Development of the Mobile Satellite Communication Simulator", Annual Research Report, 1997.

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