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PERFORMANCE EVALUATION OF LEOS SYSTEMS IN THREE-DIMENSIONAL MODEL

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ABSTRACT

This paper presents a novel three-dimensional traffic distribution model aimed at enhancing the analysis and design of Low Earth Orbit Satellite (LEOS) communication systems. The model incorporates both spatial and temporal variations in user traffic, offering a more realistic view of demand by integrating factors such as geography, population distribution, and socio-economic conditions. Unlike traditional models that often assume uniform traffic patterns, this approach captures the dynamic and nonuniform nature of real-world user behavior. The study investigates how this uneven traffic distribution influences key performance indicators, including signal quality, system capacity, and communication latency. Through detailed simulations, the findings reveal that traffic hotspots and underutilized areas can lead to inefficiencies, highlighting the need for advanced resource allocation and scheduling techniques. The proposed model provides valuable insights for improving network planning, ensuring optimal coverage, reducing congestion, and increasing the overall resilience and adaptability of LEOS-based networks in complex, dynamic operational environments.

***Keywords*:** Low Earth Orbit Satellite Communication, Traffic Distribution, Nonuniform Traffic, System Performance, Network Optimization, Resource Allocation

1 INTRODUCTION

Low Earth Orbit Satellite (LEOS) communication systems are becoming the satellite component of the third generation (3G) Mobile communication system (IMT-2000). LEOS fill gaps left uncovered by terrestrial cellular terminals. Compared to conventional geostatinary satellite system, LEOS have additional advantages such as wide area coverages, small propagation delay, loss and high elevation angle in high latitude [1]. Similarly, as in [2-3], we assume that a LEOS is in continuous motion. We estimate their performance in a period in which their movement can be ignored. The study of the geographic non-uniformity of the traffic load in LEOS communication system has been discussed in [2-3]. The previous research shows that non-uniformity in traffic makes the characteristics of the system significantly different from the results of a uniform traffic case and the quality of service of each user varies according to his location. However, they assume two-dimensional distribution traffic non-uniformity in one direction which is along the orbit under consideration. Therefore, a novel three-dimensional distribution traffic is proposed.

The rest of this article is as follows: Section II considers the traffic model. Effect of traffic non-uniformity on Signal to Interference Ratio (SIR) is given in section III. Numerical results are shown in section IV. Conclusions are given in section V.

2 SYSTEM AND TRAFFIC MODELS

Let us consider a multi orbit, multi satellite global communications network, in which, satellites are on low earth orbits of altitude, h. The number of orbits and the number of satellites on each orbit are designed so that any area on the globe may be covered by at least one satellite at any time. User's terminals have the capability of direct access with satellites in both uplink and downlink directions. As a preliminary assumption, we also assume that any user communicates with the satellite that requires the lowest transmitting power in order to minimize the total interference power on the channel. Note that in a nonfading situation, this assumption means an equal size service area for all satellites [2-3]. To establish a connection between a user and a satellite, it is necessary for that user to have an elevation angle larger than a minimum value, θ. We are especially interested in examining the effect of interference from the terminals that are located inside the service area of a given satellite and the ones that are located outside that service area. Fig.1 shows an area on the service of the earth covered by a satellite denoted by S_0 and service areas of its six neighboring satellites S_1 to S_6. As specified in the figure:

- A circle on the surface of the earth represents the coverage area of a satellite. Its center lies on the line joining the satellite and the center of the earth, and whose radius is determined by the minimum elevation angle, θ, that an earth station is assumed to be able to access the satellite.

- Double coverage areas are the overlapping of two coverage circles.
- The service area of a satellite is the hexagon drawn inside the coverage area, with sides dividing the double coverage areas.
- The interference area of the satellite S_0 is the area determined by the final line of sight of the satellite S_0. It is represented by a circle concentric with the satellite coverage circle and with radius r_I to be determined below.

The parameters of our traffic model are related to that of the previous two-dimensional model [1], through the following parameters x, r_0 and r_I. x is the location of any point on the X-axis and is determined by: $x = R\alpha$, where α is the angular distance of any user from the center of the earth and R is the radius of the earth. The distance between two neighboring satellites is $2r_0$ where: $r_0 = R\pi/N_s$, and the radius of the interference circle of S_0, r_I is given by: $r_I = R\ \beta_I$,

where

$$\beta_I = \cos^{-1}\left(\frac{R}{R+h}\right)$$

It should be noted that if an earth station lies in the interference area but out of the service area of a satellite, it would not be allowed to connect to that satellite, but still its signal reaches that satellite as interference.

In order to analyze the influence of traffic non-uniformity, we model the location of any user by two random variables x and y as shown in Fig.1 which have a normal bivariate function [1,3].

$$P(x,y) = \frac{A}{\omega^2\sqrt{1-\rho^2}}\exp\left[\frac{x^2-2\rho xy+y^2}{-2\omega^2\left(1-\rho^2\right)}\right] \tag{1}$$

Where ρ is the correlation coefficient, which reflects the geographical nature of the area.

Figures (2-a, 2-b, 2-c, 2-d) show the distribution for various values of ρ, ω.

For ρ =0 we have

$$P(x,y) = \frac{A}{\omega^2}\exp\left[\frac{x^2+y^2}{-2\omega^2}\right] \tag{2}$$

In (1) and (2) x and y are the cartesian coordinates of a user from the point that has the highest probability for existence of users, which we refer to as the origin, and ω is a parameter that shows how dense the terminals are distributed around this origin. The parameter$A$ is a normalization parameter to be determined below.

We focus only on the central satellite S_0 and its six neighboring satellites S_1 to S_6 and define the total traffic for the seven satellites, B as the traffic in their Service areas and is given by

$$B = \iint_D P(x, y) dxdy \qquad (3)$$

where D, the domain of integration is the total service area of all the seven satellites (S_0 to S_6) under consideration.

According to this assumption, A in (1) and (2) becomes

$$A = \frac{B\omega^2 \sqrt{1-\rho^2}}{\iint_D \exp\left[\frac{x^2 - 2\rho xy + y^2}{-2\omega^2\left(1-\rho^2\right)}\right] dxdy} \qquad (4)$$

and for ρ =0

$$A = \frac{B\omega^2}{\iint_D \left[\frac{x^2 + y^2}{-2\omega^2}\right] dxdy} \qquad (5)$$

The Traffic Ratio (TR) between the satellites S_0 and S_1 is given as:

$$TR = \frac{\iint_{ServiceAreaS_0} P(x, y) dxdy}{\iint_{ServiceAreaS_1} P(x, y) dxdy} \qquad (6)$$

Integrals are evaluated easily by variable transformation to polar coordinates. This ratio reflects the distribution of the traffic load among neighboring satellites.

3 EFFECT OF TRAFFIC NON-UNIFORMITY ON SIR

Utilization of power control is necessary in code division multiple access (CDMA) to limit multiple access interference and to maximize the system capacity. Users transmitting powers are controlled in order to ensure that all signals to the connecting satellite are received at the same value.

As in [4], we assume that each earth station detects the required transmission power levels of all visible satellites, by measuring the power of the pilot signal from the satellites and then connects to the one which needs the lowest transmitted power level.

For the minor effect of shadowing and fading in satellite communication environment, we can assume that the signal attenuation is proportional to the square of the propagation distance. Using this assumption, the transmitted power level required of the i[th] satellite is

$$P_i(x,y) = K_i L_i^{-2}(x,y) \qquad i = 1,2,...,N_s$$

where $L_i(x,y)$ is the distance between the i[th] satellite and the earth station and K_i is the designed receiving power level of the signals at the i[th] satellite.

The total interference is then given by [5, 6]:

$I_{total} = I_0 + I$, where

$$I_0 = \iint_{ServiceAreaS_0} P(x,y)dxdy \tag{7}$$

is the interference from the service area of the satellite S_0, and

$$I = \iint P(x,y)\min(P(x,y))L^{-2}(x,y)dxdy \tag{8}$$

is the interference reaching S_0 from the user terminals working with neighboring satellites. The integration is performed on the part of interference area of S_0 which lies outside the boundary of its service area. The interference I can be written in the form:

$$I = \sum_{i=1}^{6} I_i \tag{9}$$

Due to geographical symmetry I can be expressed as:

$I = 2[I_1 + I_2 + I_3]$

where

$$I_1 = \int_{\pi/3}^{2\pi/3} \int_{r_0}^{r_1} P(x,y)\frac{h^2 + 4r_0^2 + r^2 - 4rr_0 Sin(\theta)}{h^2 + r^2} rdrd\theta \tag{10}$$

$$I_2 = \int_{0}^{\pi/3} \int_{r_0}^{r_1} P(x,y)\frac{h^2 + 4r_0^2 + r^2 - 4rr_0 Cos(\theta - \pi/6)}{h^2 + r^2} rdrd\theta \tag{11}$$

$$I_3 = \int_{5\pi/3}^{2\pi} \int_{r_0}^{r_1} P(x,y) \frac{h^2 + 4r_0^2 + r^2 - 4rr_0 Cos(\theta + \pi/6)}{h^2 + r^2} r dr d\theta \quad (12)$$

I_0 is the interference caused by user terminals working with S_0. I_1 is the interference caused by user terminals working with S_1 or S_4 within the interference area of S_0. I_2 is the interference caused by user terminals working with S_2 or S_5 within the interference area of S_0. I_3 is the interference caused by user terminals working with S_3 or S_6 within the interference area of S_0.

4 NUMERICAL RESULTS

In this section, we evaluate the traffic ratio and the effect of nonuniformity on the *SIR* performance of LEOS system using a novel three-dimensional distribution traffic. A typical LEOS system with 6 orbits and 11 satellites per orbit is considered. The orbit altitude *h* is 800 km. The total number of users *B* in the area under consideration is 230. Fig. 3 shows the traffic ratio against the measure of nonuniformity in traffic when $\rho = 0$, $\rho = 0.4$ and $\rho = 0.8$ for S_0 / S_1. The figure shows that as ρ decreases, the traffic ratio decreases and that the results for ρ =0 are the same as in the case of two-dimensional. Fig. 4 shows the relation between SIR and ρ for different nonuniformity parameter ω. The figure shows that as ω increases, the SIR increases and that for a certain ω, the SIR is almost the same for small correlation coefficient. Fig. 5 shows the relation between SIR and ω for different correlation coefficient parameter ρ. The figure shows that as ρ increases, the SIR decreases and that for a certain ρ, the SIR is almost the same for small nonuniformity.

5 CONCLUSIONS

Three-dimensional analysis of the parameters of LEOS shows that the traffic ratio between the two adjacent satellites S_0 and S_1 is dependent on the correlation parameter ρ. The signal to interference ratio at any satellite is affected by users located in its coverage and working with six neighboring satellites. The effect of four of these satellites was neglected in the previous work. Depicted results show that the signal to interference of the central satellite is not affected by the correlation coefficient for high ω. For ω = 0.5, and ρ = 0.8, about 1dB degradation in SIR is observed. That is to say that the performance is affected by the distribution parameters ω and ρ. This suggests that, in any admission control treatment or any other method used to balance the satellite traffic loads, these area dependent parameters should be taken into consideration.

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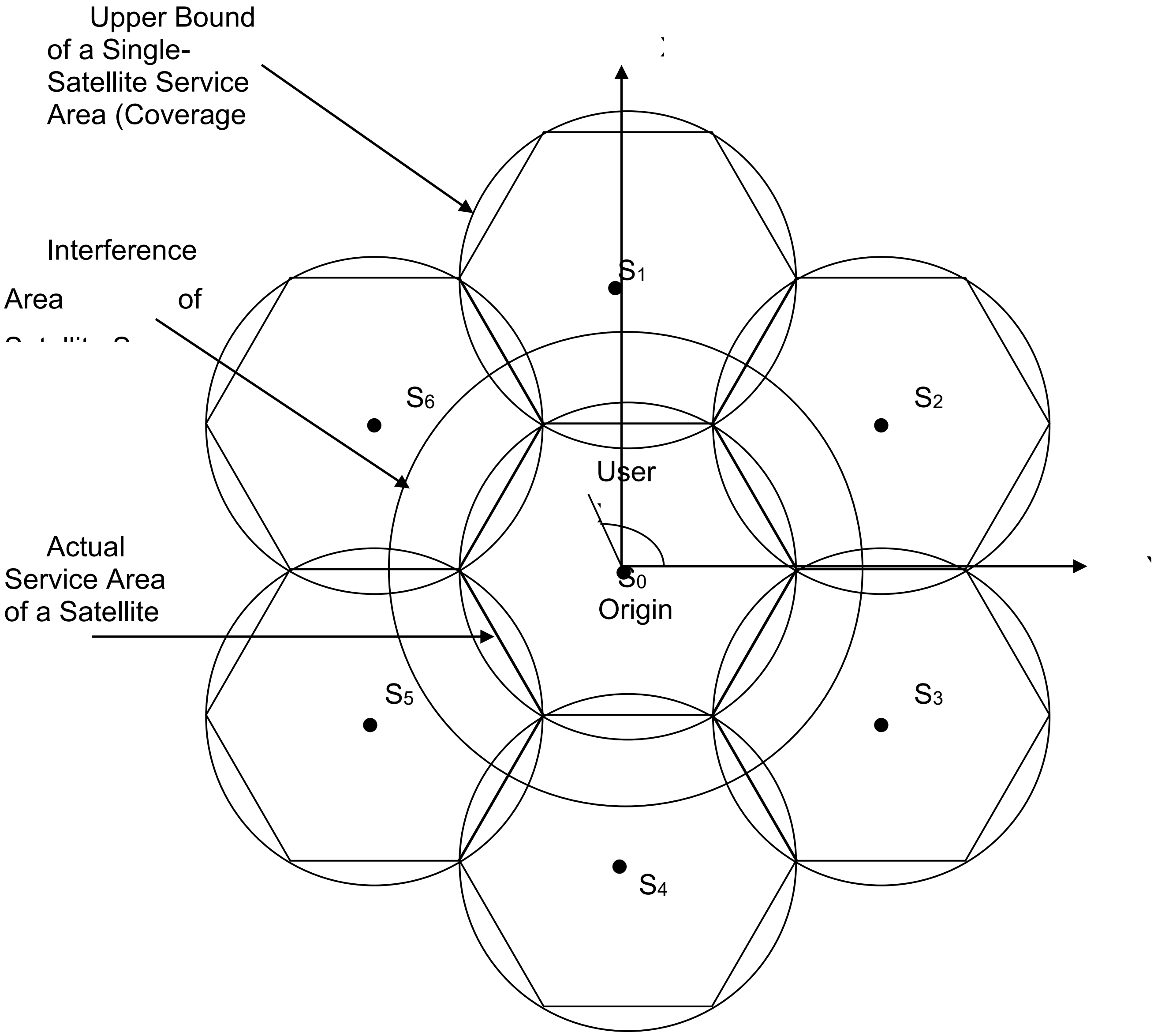

Fig.1 Configuration of service areas in the LEO satellites system

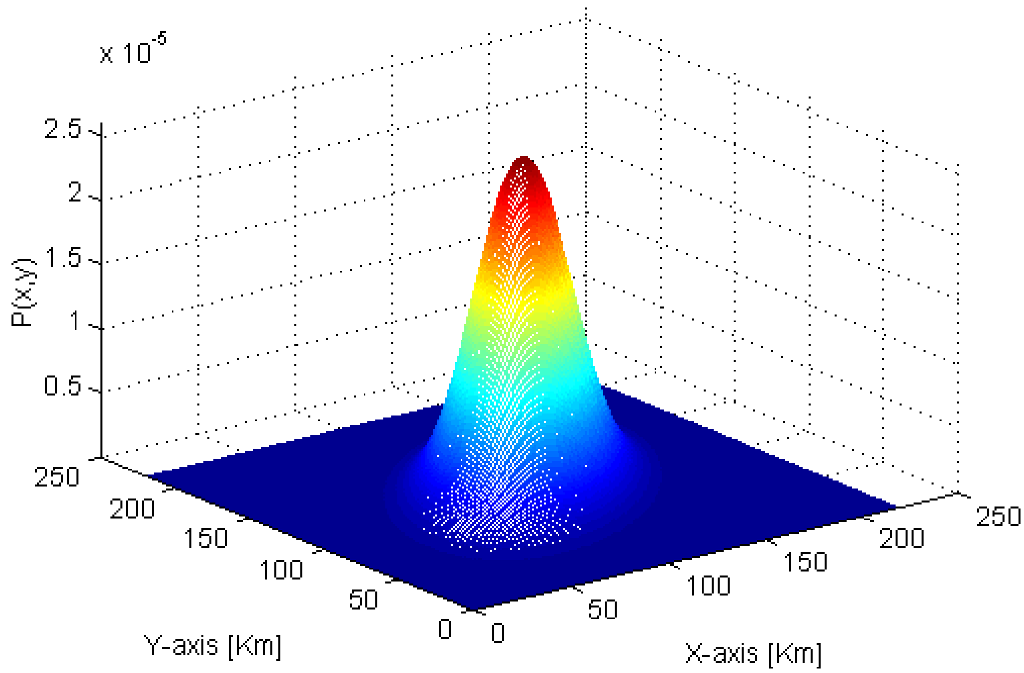

Fig. 2-a The distribution of the users in case of three dimensions for ρ=0.5 and ω=0.2

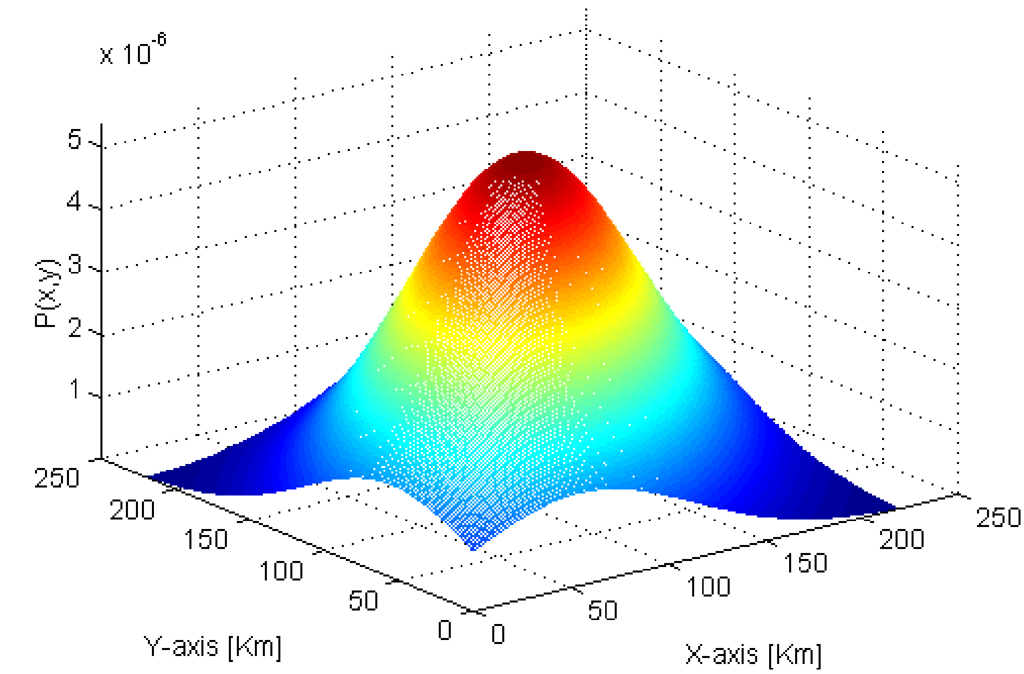

Fig. 2-b The distribution of the users in case of three dimensions for ρ=0.5 and ω=0.5

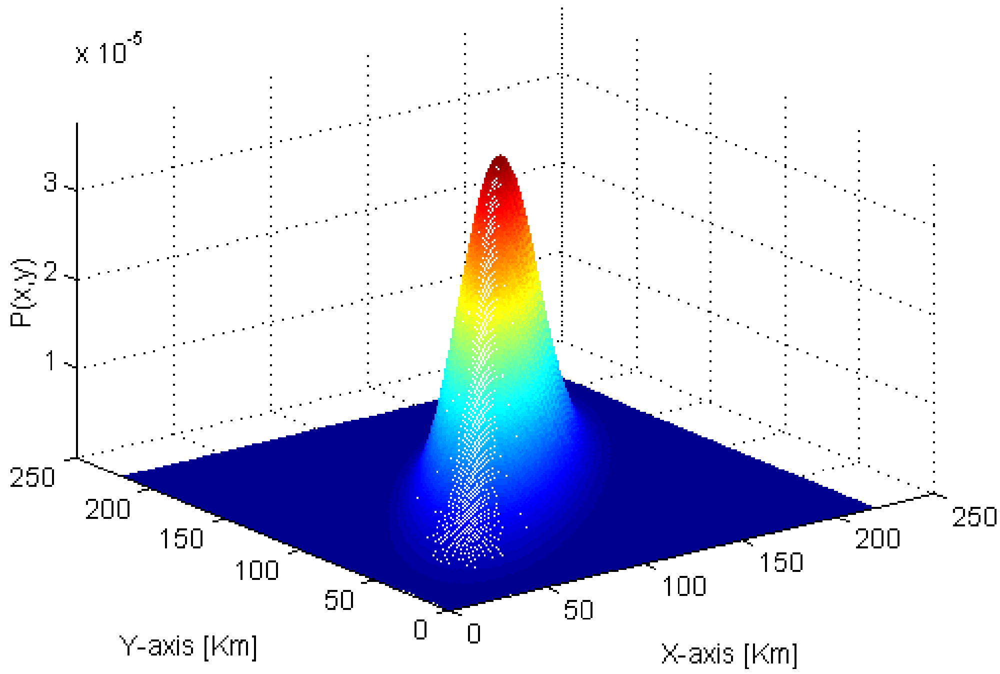

Fig. 2-c The distribution of the users in case of three dimensions for ρ=0.8 and ω=0.2

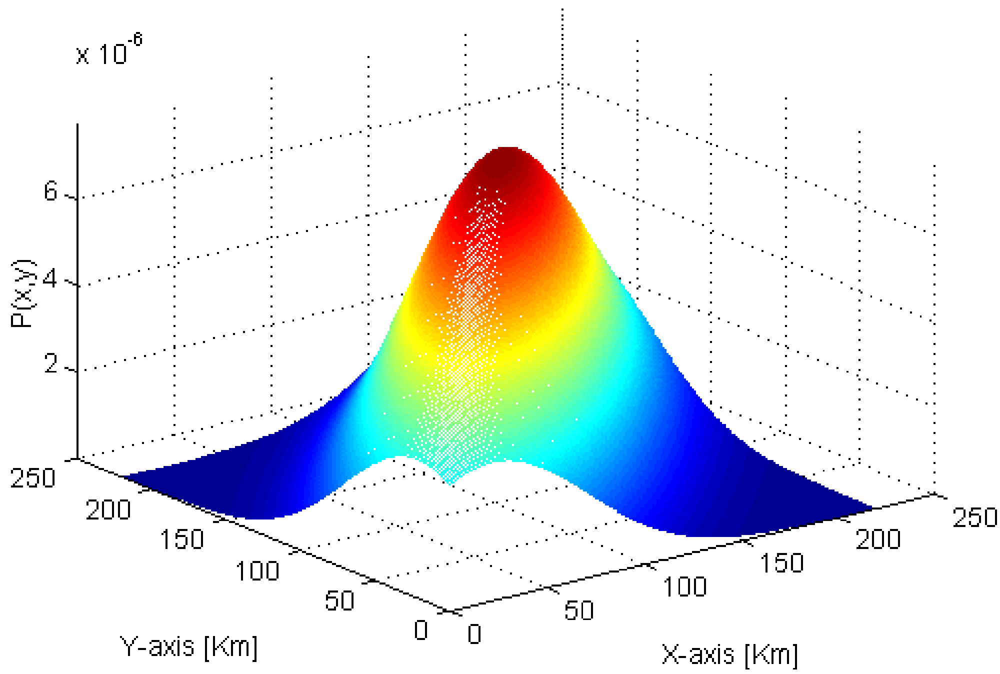

Fig. 2-d The distribution of the users in case of three dimensions for ρ=0.8 and ω=0.5

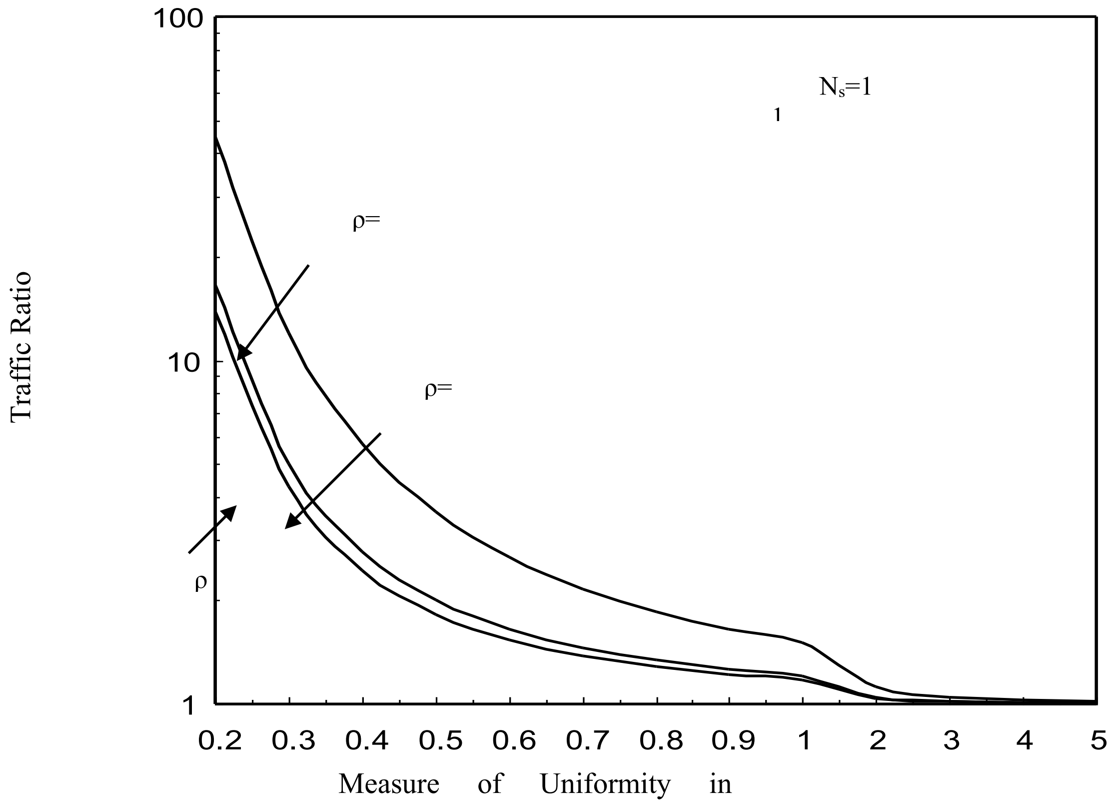

Fig.3 Traffic ratio in the service area of two adjacent satellites

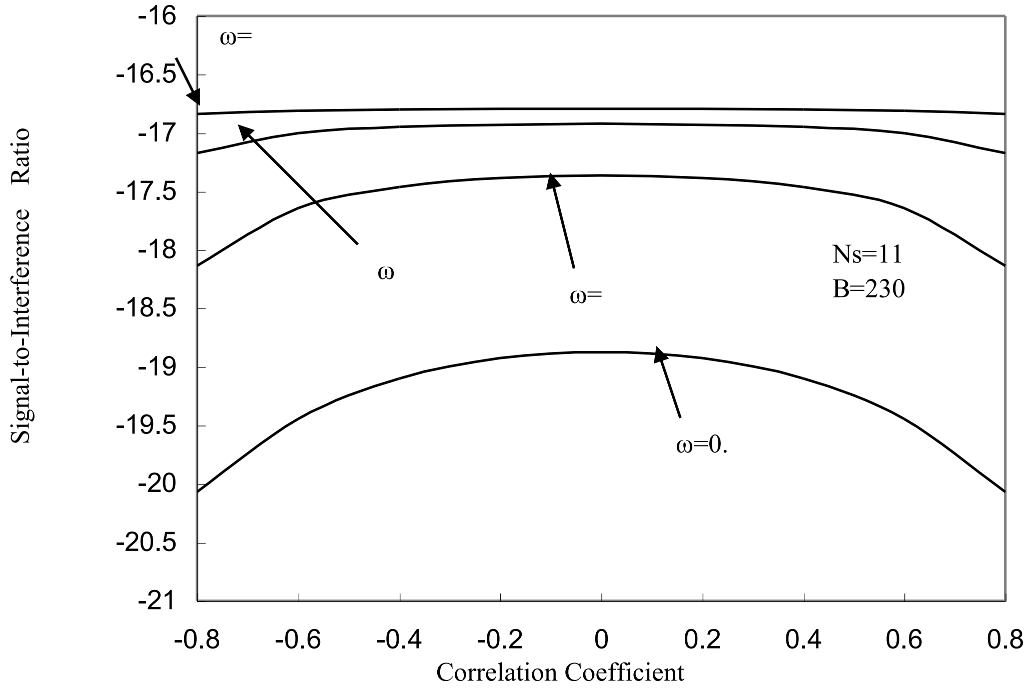

Fig. 4 Signal-to-interference ratio characteristics as a function of correlation coefficient for different values of ω

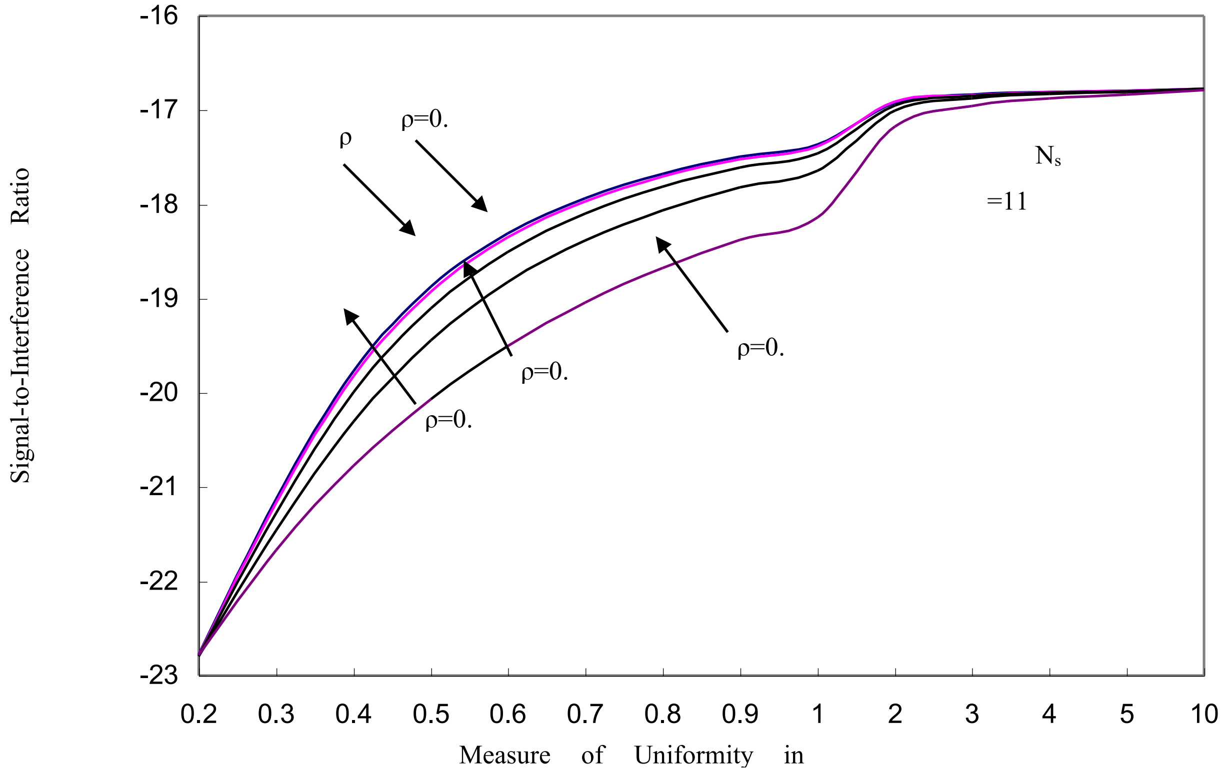

Fig. 5 Signal-to-interference ratio characteristics as a function of traffic nonuniformity for different values of correlation coefficient ρ