Performance of an Integrated Voice/Data System in Nonuniform Traffic Low Earth-Orbit Satellite Communication Systems

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***Abstract*— In some recent studies, the use of low earth-orbit satellites in various applications is considered. In all of these studies, uniform distribution of traffic load is assumed. In this paper, the performance of a low earth-orbit satellite communication system which is designed to service to two kinds of users; i.e., voice users and data users is estimated. The distribution of population of these users is assumed to be nonuniform. According to the simulation results, it is shown that the nonuniformity in traffic affects the performance of the system by decreasing the signal quality at the satellite which has to service to populated areas and increasing it superfluously at the satellite with not so populated service area, in a given period of time. By modeling the satellites during their movements, the change in signal quality while experiencing a peak of traffic load in their route is also determined. A modified power control method based on the amount of traffic load of each satellite is also examined and is shown that this method can make some performance improvements in signal quality, which is limited by special features of low earth-orbit satellite systems.**

I. Introduction

RECENTLY, so many efforts have been done to find a proper way of establishing an efficient global personal communication network (PCN). It is generally agreed that PCN will provide reliable, ubiquitous, and cost-effective communication services to individuals via small, portable terminals. Low earth-orbit (LEO) satellite communication systems are taking attention as one of the appropriate systems to offer PCN [1]–[3]. Maybe the most important thing related to this category of satellites is their role that they can have in providing a global communication system or at least to cooperate with other communication systems as their backups. The LEO systems, while having the most important features of conventional geostationary satellite communication systems, such as wide coverage area, direct radio path and flexibility of the network architecture, provide additional advantages for the global communication networks, e.g., small propagation delay and loss, and high elevation angle in high latitudes [4].

One of the most recent candidates for establishing the multiple-access in LEO satellite systems is code division multiple-access (CDMA). It has long been recognized that CDMA in a packet radio environment offers uncoordinated random-access channel sharing with low delay, along with spread spectrum advantages such as immunity to external interference and jamming, low probability of intercept, etc. [5]. Also compared with other conventional circuit switching methods such as time division multiple-access or frequency division multiple-access, by employing voice activity and frequency reuse by spatial isolation higher capacity of the system is achievable [6].

Although it is a normal feature of our globe that different amounts of communications are requested in different areas, there are only few studies on the effects of the nonuniform distribution of traffic and there isn't any in LEO satellite systems. In some papers, (e.g., see [7]), some influences of the traffic nonuniformity in terrestrial systems are reported. Although some concepts of these systems are also applicable in LEO satellite systems, (e.g., see [8]), because of some basic features of LEO systems, such as their service area specifications, in the case of nonuniform traffic study their results are not applicable for LEO systems.

This paper follows the reported idea in [9]–[10]. In those papers, the effect of traffic nonuniformity to the signal quality and system performance of a LEO satellite communication system, without distinguishing the transmitted information type, has been determined analytically. This paper plans to apply that idea in an integrated voice/data system, which is a more practical situation in PCN. The signal-to-interference ratio (SIR) characteristics at the LEO satellites will be determined through simulation in two steps. First, the case in which the satellites are assumed to be fixed with respect to the high traffic area in short period of time is considered and the relation between their performances and the intensity of traffic nonuniformity is estimated. After that, investigation is generalized to the real case; i.e., during the movement of satellites. Although the main purpose here is the estimation of the performance of LEO systems in nonuniform traffic case, a modified power control method with the aim of remedying the effects of traffic nonuniformity will be also discussed.

II. Static Nonuniform Traffic Concepts

A. Satellite System Model

Because of small coverage area of LEO satellites, compared with geostationary ones, for a global communication network

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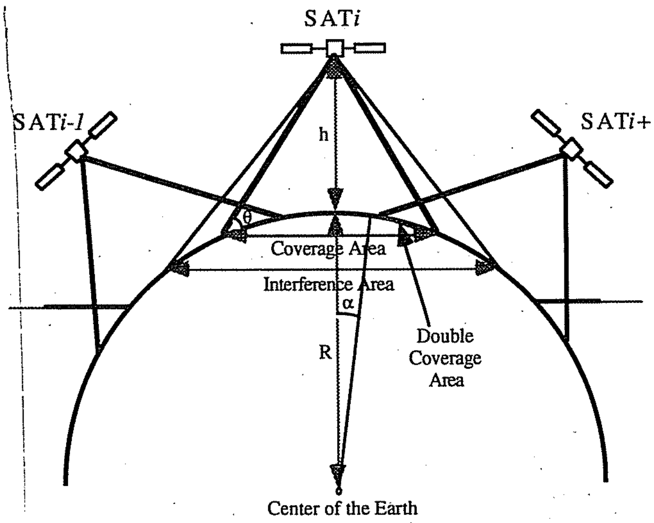

Fig. 1. Two-dimensional LEO satellite system model and the definition of the coverage area, interference area, and double coverage area.

it is necessary to organize the LEO satellites on a multiple orbit configuration. In these systems satellites are linked to each other through intersatellite links, in order to exchange the control or data information between them. Although the LEO multiple satellite communication systems are 3-D, in order to make the effect of the traffic nonuniformity more clear, we consider a simple 2-D model with a single orbit. In this model, an area on the earth is represented by an arc as is shown in Fig. 1. As specified in this figure, the coverage area of a satellite and its interference area should be distinguished from each other. The former is specified by the minimum value of the elevation angle, θ, that an earth station is assumed to be able to access to the satellite; on the other hand, the latter is determined by the final line of sight of that satellite. It should be noted that if an earth station lies in the interference area but out of the coverage area of a satellite, it would not be allowed to connect to that satellite, but still its signal reaches to that satellite as interference. In this paper the area which is located in the coverage of two satellites will be referred as "double coverage area."

Although the coverage area of a satellite specifies the maximum limits of possible access to that satellite, the actual service area of it, in which a user wishing to generate a communication automatically selects that satellite and not the other possible ones, is a function of some parameters such as required transmitting powers that those satellites request. For example, in the case where all satellites request the same transmitting power levels and with the assumption of no thermal noise, the service areas of all satellites are equal.

B. System Considerations

In this section we consider the effects of traffic nonuniformity on the performance of the system according to its reverse link (uplink), which is the limiting direction. In this direction for multiple accessing of the users to the satellite channel to transmit their packets, packet CDMA scheme is used. In this manner, we assume a simple CDMA protocol in which all user information is transmitted in the form of a sequence of fixed-length packets on the channel. Access to the satellite channel is completely unconstrained (i.e., random access) so that any given user begins transmission whenever it is ready to send data. Moreover, in our assumption there isn't any restriction on the transmitting information type and can be either voice or data type. Data traffic is sent out as a single contiguous burst at the available peak CDMA channel speed; as in ALOHA channels, packets not received successfully at the satellite are retransmitted repeatedly (after appropriate time-out) until an acknowledgment is eventually received. On the other hand, constant bit-rate stream traffic such as voice is sent as a periodic sequence of packets with the duty cycle adjusted to match the requirements of the constant bit-rate source. Stream traffic cannot normally be retransmitted, so that the receiver will have to accept the packet loss rate caused by multiuser interference. More details about realizing this kind of mixed voice/data traffic scenario can be found in some papers (e.g., see [11]–[13]).

In CDMA, in contrast to circuit-switching methods, integration of circuit-mode and packet-mode traffic requires no special protocol structure. However, in CDMA the users' transmitter powers should be controlled in such a manner that the received powers at the satellite become constant, avoiding the inbound channel receiver by close-in transmitters. As mentioned previously, in LEO satellite system after despreading the signal at the satellite, all of the simultaneous transmissions from the users located in interference area of the satellite appear as additive interference. In this paper, we assume that this kind of power control have been completely done. Also we assume that the reverse link is designed to operate at an adequate power level, so that thermal noise effects need not to be considered in the capacity and performance model.

Voice and data messages are formatted into packet as illustrated in Fig. 2. As seen in this figure, each voice packet in addition to its information bits contains synchronization preamble, network header and bit error correcting code. Continuous bit stream of voice is broken up into periodically spaced packets, each with header, synchronization and error correction overheads. Here, it is assumed briefly that the channel transmission speed, R_t, exceeds the voice encoder bit rate, R_v, and hence, the required duty cycle for transmission will be about R_v/R_t.

The actual packet size depends on error correction method which has been used. For example, with BCH coding capable of correcting n bits error, the packet size, L, and the number of the bits of information including network header residing in data field, N, satisfy the relation of $N = L - n\log_2 L$, [11], where $n\log_2 L$ gives the number of bits of error correction field of transmitting packet. Except the last voice packet which may have less than N bits of information, others exactly have N bits of information in their data fields.

In the case of data packet transmission, since the data message is transmitted as a contiguous sequence of L bit packets, the header and synchronization bits are necessary to transmit only at the beginning of the message. Therefore in this case, only the data field of the first packet contains the network header bits and similar to voice packets, all of the data fields of the packets, except the last one, exactly have N bits of data.

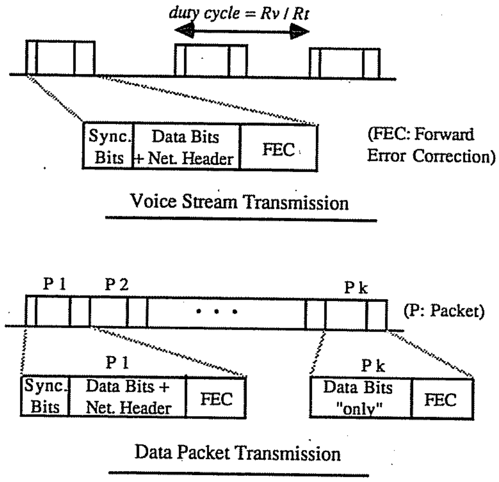

Fig. 2. Formatting of voice and data packets for transmission on uplinks.

Unless the acknowledge signal for correct reception of entire packets of message is received by the user, a data message is assumed to be in error; hence, after an appropriate time-out an ALOHA-type retransmission procedure is executed by the transmitter. This procedure executes until the message is successfully received and acknowledged by the connected satellite.

C. Traffic Modeling

In order to analyze the influence of the nonuniformity in traffic, let's define the distribution function of population of the users be able to access to the satellite communication system as

$$a(\alpha) = \frac{A}{W} \exp\left(-\alpha^2/2W^2\right), \qquad |\alpha| \leq \pi \tag{1}$$

where α is the distance from the maximum traffic point measured by the angle at the center of the earth, W is the parameter representing uniformity of traffic, and A is a factor related to the total traffic load and will be explained later. With this definition, the traffic nonuniformity is expressed by W, and when it approaches infinity, uniform distribution will be achieved. In this section, we assume the instant where the peak of traffic lies just under the satellite named dense traffic satellite (DTS), and for a given short period of the time, the change of the relative position of the peak of the traffic to the satellite is ignored. In addition, in order to make the discussion simple, we focus only on the DTS and its first right-hand and left-hand neighbor satellites (although in the calculations, at least the effects of five satellite are considered), which are named sparse traffic satellites (STS), and define the total fixed traffic load, B, for these three satellite between $\pm(3\pi/N_s)$, where N_s is the number of the satellites in each orbit. According to this assumption, A in (1) becomes

$$A = B \bigg/ \int_{-3\pi/N_s}^{+3\pi/N_s} \left[\exp\left(-\alpha^2/2W^2\right)/W\right] d\alpha. \tag{2}$$

The ratio of the traffic under DTS and each STS

$$\int_{-\pi/N_s}^{\pi/N_s} a(\alpha) d\alpha \bigg/ \int_{\pi/N_s}^{3\pi/N_s} a(\alpha) d\alpha$$

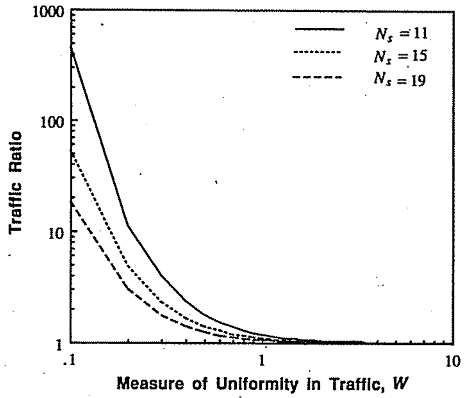

Fig. 3. Ratio of traffic in service area of two adjacent satellites, the first one is over the traffic peak, for different numbers of satellites.

is shown in Fig. 3, for different number of satellites in each orbit.

The population of the users is divided into two sets: voice users, $N_{\nu_i}(t)$, and interactive data users, $N_{d_i}(t)$, where the subscript i shows their relation to the i th satellite, measured at the time of process, t. Any user lies only in one of these two sets and not both of them simultaneously. Call (message) generation rate of the users of these two sets are λ_ν (calls/s/user) for voice users and λ_d (messages/s/user) for data users, both with exponential inter arrival time and independent to the satellite which they connect. At any instant a user is assumed to be in only one of two states; i.e., busy or idle, according to its involvement in a call (data message) transfer. New arrivals are generated only by the idle users; i.e., the users which have completed their calls (have been acknowledged their data messages). A voice call is assumed to originate a continuous bit stream at a constant rate of R_ν kb/s, with an average holding time (exponential distribution) of T_c (s). A data user is also assumed to generate packets from an exponential message length distribution with average length of M kbits. These information are transmitted on satellite channel with transmission speed of R_t kb/s.

In the case of data transmission, packets those are failed to receive at the destination or are received with uncorrectable errors, are not acknowledged and hence with a random delay, they will be retransmitted. Retransmitted packets enter the channel by the rate of λ_r (messages/s). Since the probability of successful transmission is a function of the packet length, the average length of retransmitted messages differs from M for generated messages and has the value of M'; however, its distribution can be assumed to be the same as generated messages; i.e., exponential message length. Appropriate selection of retransmission delay in packet CDMA channel using ALOHA protocol is an important factor insuring stability [14]. The equilibrium value of λ_r, the retransmission packet rate, depends on this delay and also the rate of collision on the channel. At equilibrium, the total packet inflow and outflow rates should be equal. Having this fact and with a procedure similar to the one used in [15], the average length of the retransmitted message M' and retransmitted packet rate λ_r are searched numerically throughout the simulation. Fig. 4 summarizes the traffic load offered to the channel at the time of process.

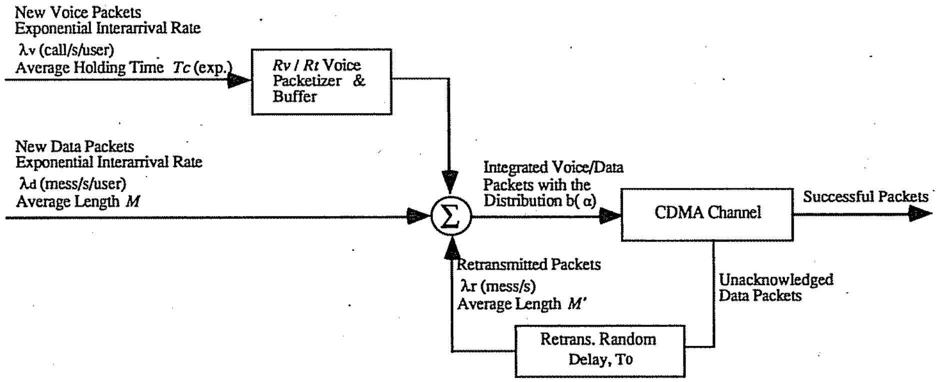

Fig. 4. Offered traffic load to CDMA channel.

To apply the equilibrium condition, it is necessary to find the probability of packet success first. At each satellite and in absence of thermal noise, the packet error is caused by the interference from all users lying in the interference area of that satellite. At the network analysis level, for many spread spectrum schemes, it is possible to model the channel interference by summing the interference powers and treating this sum as Gaussian noise [16].

When the interference assumed as Gaussian noise, we can define the equivalent bit energy-to-noise ratio at the ith satellite, μ_i. Let the packets modulate by direct-sequence scheme with binary phase shift-keying (DS/BPSK) with rectangular chip pulse. Then from the result of Pursley [16], it can be shown that

$$\mu_i = \left(\frac{2I_i}{3\Gamma S_i}\right)^{-1} \tag{3}$$

where, Γ is the bandwidth expansion factor, I_i and S_i are the total power of interference and the received power at the ith satellite, respectively. Note that I_i is the sum of the interference powers of those packets which are transmitted in service area of the ith satellite and in service area of the neighbor-satellites but in interference area of the ith satellite as well. By this model, the probability of bit error can be approximated by

$$p_e = 0.5 \text{ erfc}(\sqrt{\mu_i}) \tag{4}$$

where erfc$(\cdot)$ is the complement of the error function. The probability of packet success conditioned on μ_i is defined as

$$P[\text{success of observed packet } \mid \mu_i] = s(\mu_i). \tag{5}$$

The function $s(\cdot)$ is a smooth function of signal-to-interference ratio, depends on the adoption of error-correcting code, and with powerful error correction codes it approaches to a step function at some threshold value of SIR at the satellite. The unconditional packet success probability can be calculated by $s(\cdot)$ with respect to the probability density function of μ_i, over all possible values of μ_i.

Since for any value of SIR the probability of packet success and hence, the expected number of successfully transmitted packets, or throughput, are resulted, in this paper we employ SIR characteristics as the performance measure of the system and discuss the throughput performance in a more specified system in another place [17].

D. Simulation Environment

In order to estimate the SIR characteristics of LEO satellite system in the presence of nonuniform time-varied traffic, a simulation model based on the traffic model explained in last subsection is used. In this model, a typical LEO satellite system with 11 satellites on the altitude of 1500 km is assumed. In each processing interval period of the simulation program, T, the traffic uniformity parameter W changes by the equal steps of ΔW from a maximum value (for nearly uniform traffic load case) to a minimum value (for a peaked traffic case).

In our simulation model the multiuser interference power faced to each packet transmitted to the satellite under process is the sum of two parts. The first part is due to the existing packets generated by the users in coverage area of this satellite *and* select it as communication satellite; and, the second part is the interference from external users in adjacent satellites' coverage areas *and* in line of sight of the satellite under process. Both of these interferences are determined as a function of the number of new generated packets, retransmitted packets and continued packets from last trials, in every trial according to duration time of their connections. Without restricting our discussion on hand-off performance of the system, here we assume that a perfect hand-off procedure for the users has been done; that is, any active user (a user in a busy state) at any instant is communicating with the satellite which that user lies in its coverage area *and* offers the minimum required transmitting power to that user. Table I summarizes the simulation parameters used for evaluation of the performance of the LEO system.

Although it is said that the spatial reuse of frequencies and voice activity are important points to increase the capacity of CDMA [6], we do not explicitly include them in our model. The reason for no consideration of voice activity is that the low bit-rate speech coding under consideration here indirectly exploits short-term burst effects to some degree. On the other hand, the efficiency of spatial reuse in CDMA depends on a number of factors, including the multiplexing efficiency of the CDMA code and the modulation technique employed, which

TABLE I
SIMULATION PARAMETERS

Item	Symbol	Value
Channel transmission speed (kbps)	R_t	20
Voice encoder bit rate (kbps)	R_v	8
Packet size (bit)	L	256
Max. no. of correctable errors per packet (bit)	n	10
Synchronization overhead per packet (bit)	—	10
Call generation rate of voice users (call/s/user)	λ_v	0.0005
Message generation rate of data users (mess/s/user)	λ_d	0.1
Average holding time of voice users (min)	T_c	3
Average length of message (kbit)	M	1
Retransmission time-out limit (s)	T_O	60
Processing interval time (s)	T	10

are not necessary to express precisely here for the purpose of our comparison.

E. Performance Measurement

In order to realize the equal channel sharing and make the capacity maximum, the transmitting power control of each user is the basic system requirement in CDMA. For this purpose, the transmitter powers of the earth stations are controlled so that all users' transmitted signals reach to the connecting satellite at the same level. In this paper, 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 for example [6], and then connects to the one which needs the lowest transmission power level.

In the case of satellite systems, because of relatively small effect of shadowing and Rayleigh fading, it is reasonable to assume that the radio signal power is attenuated in proportion to the second power of propagation distance. By this assumption, the required transmitter power level that the ith satellite demands for the earth station at position α is

$$P_i(\alpha) = C \cdot S_i \cdot l_i^2(\alpha), \quad i = 1, 2, \cdots, N_s \tag{6}$$

where S_i is the required power level of the signals at the ith satellite, C is a constant with the dimension of inverse of squared-distance depends on the wavelength of the carrier [18], and $l_i(\alpha)$ is the distance between the ith satellite and the earth station at the angular position α. If the angle between the ith satellite and the peak of the traffic is β_i, the distance $l_i(\alpha)$ becomes

$$l_i(\alpha) = \left[(R + h - R\cos(\beta_i - \alpha))^2 + R^2 \sin^2(\beta_i - \alpha)\right]^{1/2} \quad i = 1, 2, \cdots, N_s \tag{7}$$

where R is the average radius of the earth, about 6370 km, and h is the altitude of satellites. As mentioned in the preceding section, we assume the case where the peak of the traffic lies just under one of the satellites. Now let the ith satellite be DTS, the $(i-1)$th and the $(i+1)$th ones be STS. Then we have

$$\beta_{i-1} = \alpha - \gamma, \quad \beta_i = \alpha, \quad \beta_{i+1} = \alpha + \gamma$$

where $\gamma = 2\pi/N_s$ is the angle between two adjacent satellites.

When the reverse link is designed to operate at an adequate power level, in CDMA systems, the effect of thermal noise is generally smaller than that of interference and hence SIR is a proper measure of the system performance. The signal sent to the ith satellite arrives at that satellite with the power S_i and all other simultaneous transmissions from the users located in its service area and its interference area, appear as additive interference at that satellite. Thus, the SIR at the ith satellite becomes

$$(\text{SIR})_i = S_i / I_i \tag{8}$$

where I_i is the interference at the ith satellite, described as

$$I_i = (1/C) \int b(\alpha) \cdot \min(P_i(\alpha)) \cdot l_i^{-2}(\alpha) d\alpha, \quad i = 1, 2, \cdots, N_s \tag{9}$$

where $\min(x)$ is the minimum x corresponding to every i and $b(\alpha)$ is the distribution of the packets transmitted at the time of process by users of (1), including new generated packets, retransmitted packets, and continued packets distributions. The interval of the integration will be discussed in the followings.

As a result of circularity of the earth, transmitting signals from users angularly located further than β_i from a given satellite does not reach to that satellite, where

$$\beta_I = \cos^{-1}(R/R + h) \tag{10}$$

is the interference limit angle, and if $\beta_I < 3\gamma/2$ the interval of the integration in (8) for DTS becomes from $-\beta_I$ to β_I, and by symmetry of the model, the power of interference at the ith satellite (DTS) is

$$I_{\text{DTS}} = I_i = 2\left[S_i \int_0^{\gamma/2} b(\alpha) \cdot l_i^2(\alpha) \cdot l_i^{-2}(\alpha) d\alpha + S_{i-1} \int_{\gamma/2}^{\beta_I} b(\alpha) \cdot l_{i+1}^2 \cdot l_i^{-2}(\alpha) d\alpha\right] \tag{11}$$

where the first term in the bracket denotes the interference from the users of DTS and the second is that from the users of STS. Similarly, interference at STS can be found as

$$\begin{aligned} I_{\text{STS}} = I_{i-1} = I_{i+1} &= S_{i+1} \int_{\gamma/2}^{3\gamma/2} b(\alpha) d\alpha \\ &+ S_i \int_{\gamma-\beta_I}^{\gamma/2} b(\alpha) l_i^2(\alpha) l_{i+1}^{-2}(\alpha) d\alpha \\ &+ S_{i+2} \int_{3\gamma/2}^{\gamma+\beta_I} b(\alpha) l_{i+2}^2(\alpha) l_{i+1}^{-2}(\alpha) d\alpha \end{aligned} \tag{12}$$

where the first term is the interference from its own users and the second and third ones are from users of both sides. It should be noted here that since the effects of the other satellites are being out from the interference area of the satellite under

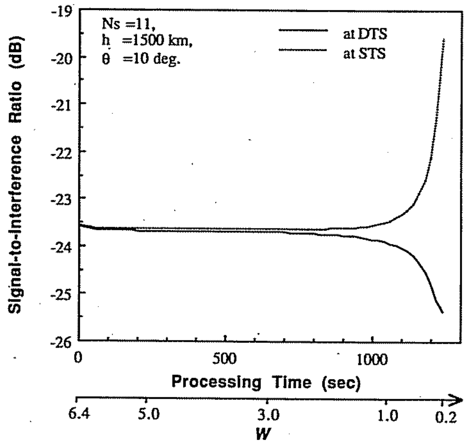

Fig. 5. SIR characteristics at dense traffic satellite and sparse traffic satellite as a function of traffic uniformity for equal population of voice and data users.

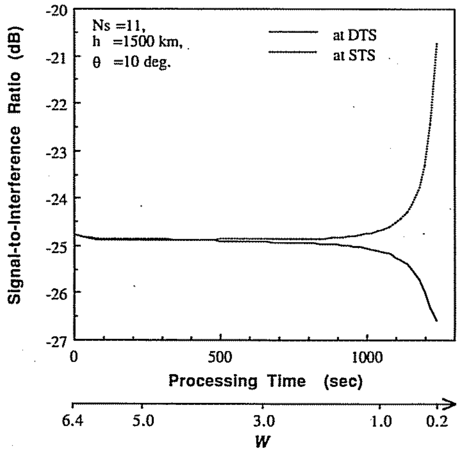

Fig. 6. SIR characteristics at dense traffic satellite and sparse traffic satellite as a function of traffic uniformity for the ratio of data users to voice users equals 2.

process, only the first order neighbor satellites' users are considered here.

Let us assume that all satellites request the same power levels to the users, thus $S_i = S$ for $i = 1, 2, \cdots, N_s$. Then the assumption of connecting a given earth station to the lowest required power satellite, results in connection to the nearest satellite from that station. Fig. 5 indicates the simulation result of SIR characteristics, at the both DTS and STS for $\theta = 10°$, $h = 1500$ km, and $N_s = 11$ as a function processing time, assuming equal population of voice and data users. In this figure, simulation procedure starts at $t = 0$ with a large value for $W (W > 5)$ as relatively uniform traffic case and finishes at $t = 1260$ s with a nonuniform peaked traffic ($W = 0.2$). From this figure we can find a large difference of the signal quality for DTS and STS. At high traffic nonuniformity, the SIR of DTS degrades notably, while STS marks superfluous quality. We can conclude that the large traffic nonuniformity (e.g., $W < 0.2$) decreases the system efficiency, significantly. It should be noted that the traffic nonuniformity of $W = 0.2$ still is not so large nonuniformity; that is, with respect to Fig. 3, the ratio of traffic under DTS to traffic of STS for this value of W is something about 10, however, the difference in their SIR

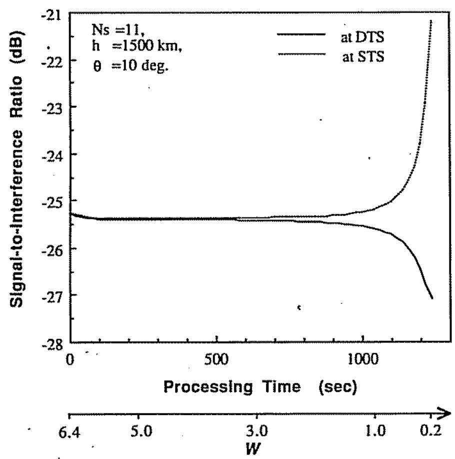

Fig. 7. SIR characteristics at dense traffic satellite and sparse traffic satellite as a function of traffic uniformity for the ratio of data users to voice users equals 3.

becomes about 6 dB. Although here is not shown, with lower altitude of satellites this difference becomes larger (e.g., with $h = 800$ km, this difference increases to 13 dB). This large difference is a direct result of the necessity of connecting the users to the nearest satellite. In addition, since for the users locating in single coverage area of a given satellite there isn't any other selection for connecting to the other satellites at a given period of time, they have to accept this large multiuser interference and its followings.

Figs. 6 and 7 show the SIR characteristics at DTS and STS with the same satellite system constellation parameters as Fig. 5; but for different ratio of population of data users to voice users. Comparing these three figures, it is concluded that by increasing the ratio of the data users to voice users, keeping the total number of users fixed, the performance of the system even in uniform traffic case degrades. One reason is the retransmission permission which the data users have. However, the ratio of data users to voice users seems not to be considerably effective on large divergence in the characteristics of DTS and STS in nonuniform traffic situations.

III. Dynamic Nonuniform Traffic Concepts

A. Dynamic Feature of LEO Satellite Systems

In preceding section, we analyzed the effect of traffic nonuniformity in LEO satellite systems by defining a nonuniform traffic probability density function, which had a single peak through the coverage areas of three adjacent satellites. In that analysis, it was assumed that at the instant of process, this single peak is lied just under one of the satellites, made its traffic load dense, hence adopted the name of dense traffic satellite, and consequently, the name of its two first neighbor satellites became sparse traffic satellites, according to their low traffic loads compared with the traffic load of DTS, ignoring the change of the relative position of this peak to the satellites. This assumption leads our analysis to investigate through a special situation, which may have a particular role at the design procedure time. Although the LEO satellites are in continuous motion in their orbits and hence their network topology is highly dynamic, this kind of assumption that the system constellation is static for a small period of time, is reasonable, as in some papers this situation refers to quasi-stationary arrangement of the LEO satellites (e.g., [2]).

More exactly speaking, we should notify that the traffic loads in coverage areas of the LEO satellites are not only nonuniform but also changing as a function of time, as result of two phenomena. The first one is for the natural feature of telecommunications systems, that is, the changes in total number of the users in different hours in a day at the same area, nonuniformity in call arrival and call arrival density, etc. However, the second one is a direct result of moving property of LEO satellites, from viewpoint of a fixed object on the earth. Precisely speaking, this object should not be named fixed, when remembering the high speed of the LEO satellites (e.g., with a typical value of $h = 1500$ km, LEO satellites have a linear speed about 7.1 km/s), not comparable to the speed of any known vehicles on the ground or in the air, therefore any fixed or mobile stations can be viewed as a fixed station in LEO satellite system. Moreover in the case of LEO satellite communication system, the latter phenomenon; that is the change in traffic loads according to the movement of satellites is rapid, compared with the change related to different hours in a day. Hence it is reasonable to consider this rapid change only in our calculations, made the other constant during measurement. By this, we can apply the same LEO satellite system model as Fig. 1, again to make the effect of traffic nonuniformity more clear and the calculations simpler, only one orbit of the LEO satellite system is considered.

B. Simulation Model

To estimate the changes in characteristics of LEO satellite communication system using CDMA when the satellites experience the nonuniform traffic requests during their travels, a modified version of simulation model of Section II is used. In this model it is assumed that a nonuniform traffic distribution as (1) with predefined value of W in a specified area within the satellites trip exists. Assuming counterclockwise movement of the satellites of Fig. 1, two satellites, namely, main satellite and its first right-hand neighbor satellite, consequently experience the service of the users distributed with that distribution function. The start point of simulation is when that the main and its first right-hand neighbor satellites are in $\alpha = 2\pi/N_s$ and $\alpha = 4\pi/N_s$, respectively, far from the peak of the traffic distribution lied at $\alpha = 0$. They rotate in their orbit with the constant angular velocity $\omega_{\nu s}$ until the main and its first right-hand neighbor satellites reach $\alpha = -2\pi/N_s$ to and $\alpha = 0$, respectively. According to abbreviations of Section II, during this period the main satellite experiences three main states of traffic of STS, DTS and again STS and of course their intermediate states, consequently; however, the first right-hand neighbor satellite before reaching to STS and DTS states, starts from a very low traffic state, even less than STS's one. From Newton's law, the angular velocity $\omega_{\nu s}$ of each satellite can be found from

$$\omega_{\nu s} = (gm)^{1/2} \cdot r^{-3/2} \tag{13}$$

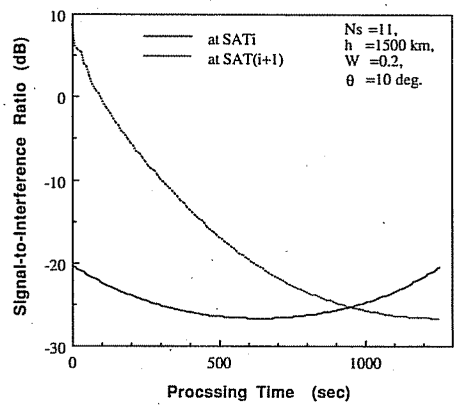

Fig. 8. Changes in SIR characteristics at the main and its first right-hand satellites as a function of processing time with equal required transmitting power levels.

[18], where $(gm)^{1/2} = 631.3482$ km$^{3/2}$/s, g is gravity constant, m is the mass of the earth, and r is the radius of the satellite orbit, equals $R + h$. From this equation and simple calculations, in this altitude the period of a complete rotation of the satellites will be about $T_s = 116$ min and hence the total simulation period with eleven satellites will be about 21 min $(2 \times T_s/N_s)$.

Except the traffic nonuniformity measure, W, which is fixed in this simulation model, other parameters of Section II stand for this simulation. Fig. 8 shows the changes of SIR characteristics at the main satellite and its first right-hand neighbor satellite as a function of processing time for $W = 0.2$, assuming equal population of voice and data users. As this figure illustrates, even in the case of not so large traffic nonuniformity as much as $W = 0.2$ (compared for example with $W < 0.1$), in not so small periods of time large degradation in SIR at the satellites occurs. This is just when at the neighbor satellites, whose their facilities generally can be accessed by the users to some degrees, their SIR have extra values. If we assume that the worst situation in system performance is the case where the signal quality at a satellite has the lowest value, from this figure, this is the case where the peak of the traffic load is lied just under one of the satellites. This figure suggests us to apply the facilities of the low traffic neighbor satellites more optimally.

C. Modified Power Control Scheme

The results have shown till now were based on this assumption that all satellites request same receiving power levels and thus the users connect to the nearest satellite. This means that any user without paying attention to the number of simultaneous transmissions and current packet loss rate of the system, is made to connect to and only to the nearest satellite. However, at least for the users locating in double coverage area of the satellites there is another chance to connect to the satellite which has smaller traffic load than the other, even its distance is larger. In this section we consider the scheme that changes the required transmitting power levels of the satellites depends on traffic loads of them.

In this method, in each processing interval period, T, the traffic load of every satellites distributed in their coverage area are measured. According to current value of required trans-

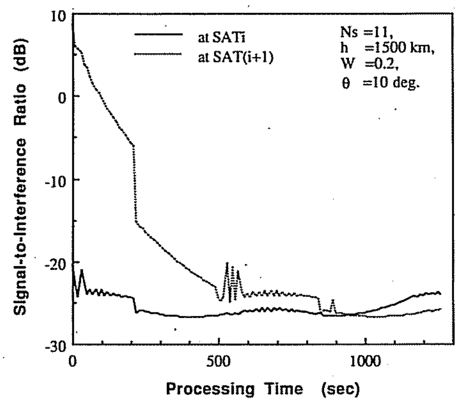

Fig. 9. Changes in SIR characteristics at the main and its first right-hand satellites as a function of processing time after applying the modified power control method.

mitting power level of each satellite, its permitted service area and consequently the value of SIR at it are also determined. The required transmitting power level of any given satellite is changed if the SIR value at it is less than a minimum threshold level and at its neighbor is more than a maximum threshold level, or vice versa. This change is performed according to the ratio of the traffic loads of that satellite and its neighbors adaptively, and is reported to the other satellites through the intersatellite network. Since the users located in coverage area of each satellite and out of its double coverage areas have to connect to that satellite only, the maximum change in required transmitting power level of each satellite is limited to the point where this change can affect to the decision of the users in double coverage areas. Any further changes in power levels only will degrade the performance of both low and high traffic satellites.

By applying this method, the required transmitting power levels of the satellites with higher traffic load become larger; on the other hand, the required transmitting power levels of low traffic ones decrease. This results in decreasing the service area of the satellite with higher traffic load. With same parameters as last subsection, Fig. 9 shows the simulation result same as Fig. 8, here after applying the above explained modified power control method. For this case, it is assumed as an example that the maximum and minimum threshold levels are -23.0 dB and -24.5 dB, respectively.

As seen in this figure, by applying this method the minimum values of SIR at these two satellites are risen by some decibels, with the expense of degrading the performance of other neighbor satellites to some degrees, however, still the characteristics of these neighbors are enough more than an acceptable value. It is important to state that this improvement should be limited to the point where does not make the performance of the other satellites worse than a reasonable value. If more satellites exist in each orbit or if the height of them becomes higher, we can expect that the method gives better performance improvement.

IV. Conclusion

This paper models the nonuniformity of the traffic loads in a satellite based communication system employing low earth-orbit satellites and analyzes the performance of the system through simulation. The users of this communication system are grouped to voice and data users, in which they transmit their fixed-length packets to CDMA uplink satellite channel. With the same required transmitting power levels requested by the satellites, it is shown that the performance of LEO system, measured by the value of SIR at each satellite, degrades as a direct result of nonuniformity in distribution of users. Also it is shown that the worst case in the performance of the satellite system happens when the peak of the traffic load lies just under one of the satellite. In addition, a modified power control method which changes the required transmitting power levels, according to the traffic loads in coverage area of satellites, is examined and is shown that this method can remedy the performance degradation of the system to some degrees.

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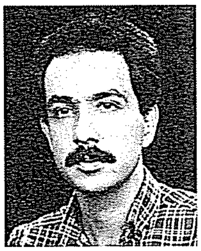

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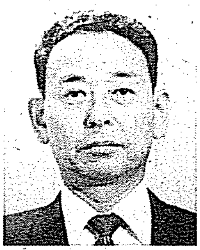

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