Satellite Diversity Gain Over The LEOS Channel, Based CDMA Systems

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Abstract: *There is a trend for mobile satellite system architectures aimed at the deployment of multi-satellite constellations in Non-Geostationary Earth Orbits (NGEOs). This allows the user terminals to be small size, low cost and having low power demand.*
In present and next generation satellite systems, CDMA has been proposed as the multiple access technique for a number of mobile satellite communication systems. To enhance the coverage and quality of service, Low Earth Orbiting (LEO) constellations are usually selected. In this paper, we analyze the performance of the downlink of a LEO satellite channel. The provision of such a service requires that the user have sufficient link quality for the duration of service. To have sufficient link quality, the user must have an adequate power to overcome the path loss and other physical impairments to provide acceptable communication and improve the performance of the system.
This paper addresses satellite diversity with the effect of both power control error and voice activity factor for downlink mobile satellite systems. Both Rician and Rayleigh channel statistics are modeled. Results of simulation show that satellite diversity has a significant effect on the system performance. Moreover, the quantitative results indicate that to combat system capacity reduction due to shadowing and the multiple access interference (MAI), perfect power control system, voice activity factor and suitable coding techniques must be employed in the system.

1. Introduction

Recently, there has been considerable interest in applying direct sequence spread spectrum *(DS-SS*) techniques to multiple access communications. This is partly due to its multiple-access capability, robustness against fading and anti-interference capability [1]. *CDMA* has some advantages over *TDMA* and *FDMA* in mobile communication applications. Some of common reasons for employing *CDMA* scheme are as follows; *CDMA* capacity is only interference limited and soft. *CDMA* signals are more tolerant than either *TDMA* or *FDMA* signals to co-channel interference. *CDMA* system can reuse the entire frequency band in each cell, since no frequency planning are used and allows simple network control [2].
As in terrestrial cellular systems, *CDMA* has also been proposed for *LEO* satellite systems. However in comparison with terrestrial mobile environments, the differential multipath delays are much smaller and the propagation delays are much larger for the satellite link (about 10-20 *ms* for *LEO*) so that instantaneous closed loop adaptive power control is not feasible due to stability issues. Furthermore, since the frequency separation between the up and down links is about 800 *MHz*, lack of reciprocity precludes the use of open loop control except for object shadowing. Therefore an open loop *CDMA* power control scheme is proposed merely to track and compensate for large-scale variations caused by shadowing and propagation losses [3].
In practice, the satellite systems tend to use multibeam antennas to increase the spectrum efficiency. The actual performance of the system will heavily depend upon the total effects of multiple access interference (*MAI*) from all users seen by the satellite, besides those in the desired spot beam. Furthermore, it must exploit the dual satellite diversity most of the time to improve the performance or reduce the link margin. The effective use of diversity techniques can reduce the required power margin, antenna size and transmit power or increase system capacity. This paper deals with the bit error rate of *CDMA*-based

multispot beam *LEO* system with satellite diversity and imperfect power control for down link. In the analysis, the power control error (*PCE*) is considered to be *Lognormal* distributed and the channel is assumed to be Rician-Rayleigh model.

The paper is organized as follows; principle of satellite diversity is described in section 2 and the system model is described in section3. Simulation results and discussion are presented in section 4. Finally, some concluding remarks are given in section 5.

2. Principle of satellite diversity

2.1- Propagation environments

In order to investigate the benefits of dual satellite diversity, the characteristic of the mobile satellite channel must be studied carefully. The channel a user encounters has a large *Doppler* shift and is a function of a number of variables such as the number of satellites visible, the elevation angle at which the satellites are seen, and blockage due to foliage or buildings in the path of the satellite.

In the downlink, the multi-path fading occurs because the received signal does not only contain the transmitted signal but also echo signals being reflected from objects in the surrounding environments. The received total power of the echoes mainly depends on the type of user environments (*urban, suburban, rural, etc*.) and on the antenna characteristic of the user terminal. For low satellite elevation angle the shadowed areas are larger than for high elevation angle. There are several channel models have been derived, describing the transmission path between a mobile/personal user and a *GEO* or N*GEO* satellites [4]-[6].

In wide-band *CDMA* systems, the multi-path environment can be exploited through the *RAKE* receiver architecture, allowing signals arriving at the receiver with different propagation delays to be independently received and combined to provide an additional gain. This is a unique feature of the *DS-CDMA* referred to as multi-path diversity.

The use of the *RAKE* receivers in terrestrial suburban and urban environments proves to be very effective due to the sufficient delay spread associated with such channels, as shown in table 1.

Table1

Environment	*Delay spread*
Terrestrial Open area	*0.3* μsec
Terrestrial Suburban area	*0.5* μsec
Terrestrial Urban area	*3* μsec
Satellite environment	$\prec$ *100 nsec*

In the satellite environment, however, delay spreads of less than 100 *nsec* are generally experienced. Hence any *CDMA* system designed to effectively make use of the spreading to resolve the multi-path would have to be spreading at least 10 *MHz* or more. Due to limited allocated spectrum to mobile satellite systems this is not possible. Therefore no significant multi-path diversity gain in satellite systems is expected. In the *LEOs* services diversity is achieved by the use of multiple satellites, known as satellite diversity. Loss of service will often be caused by the line of sight to a satellite being blocked (e.g. buildings, heavy foliage, etc.). Therefore by offering potential visibility to more than one satellite, the probability of good channel not being available to any satellite is reduced.

2.2- Satellite diversity

On the *downlink*, satellite diversity reduces the probability of shadowing by increasing the chance of having at least one satellite in a clear line-of-sight. Also it achieves an improved quality of service from two poor satellite channels. In maximum ratio combining technique (MRC), two satellites should illuminate all mobiles at all the time. Then, by going into a shadowed state with respect to one of the satellites, a mobile may experience some degradation in the performance, but can still maintain the call until the power control mechanism restores the performance level. The received signals are processed in such a way as to emphasize the stronger signals and de-emphasize the weaker signal.

The best gain in service availability can only be achieved if the considered satellite channels are independent. The effective correlation of the two channels is highly dependent on the elevation angle and azimuth separation of the two satellites with respect to the user and the operational environment.

3. System Model

3.1- Factors to be considered

The simulation model includes convolutional-coded *QPSK* modulation with soft decision decoding, perfect interleaving and a rake receiver to combine the resolved multi-path signals has been considered to optimize the channel performance. Other very important issues to take into account in the simulation model are the presence of the *MAI* and fade margin due to shadowing and fading. The channel capacity of a *LEO* satellite based on *DS-CDMA* system is analyzed including the effects of faded user interference, power control error, overlapping antenna beams, imperfect equalization of the antenna pattern across an antenna cell, and diversity reception.

We assume that each cell in the footprint has the same area and is illuminated by the main-lobe of a spot-beam. The antenna patterns are arranged so that the intersection of adjacent cells is at the *-3dB* contour. When the mobile is shadowed, its signal is given a power boost at the transmitter to compensate for the fade; when the mobile is not shadowed, we assume line-of-sight transmission. The average power enhancement due to shadowing is given by:

$$S=(1-B)^2+2.B.(1-B)+B^2.P_2 \qquad (1\text{-}1)$$

Where B is the probability of shadowing, and P_2 is the factor that represents the increasing of satellite transmits power when the mobile is shadowed from both satellites.

3.2- Beam overlap

Any practical antenna will produce energy slipover from one satellite to another. For asynchronous *CDMA* systems, the beam overlap factor is given by [7];

$$b_o=1+J_1A_3+J_2A_4 \qquad (1\text{-}2)$$

Where J_1 is the number of the adjacent cells with coupling value equal A_3 and J_2 is the number of the next-adjacent cells with coupling value equal A_4. In a satellite system, where interference falls off as distance squared, a larger value would be obtained than for a terrestrial system. In *CDMA* downlink systems, the desired signal and all interference signals arrive at the receiver from a single source satellite with the same delay Pseudo-noise codes that are orthogonal. In this case the interference from a user in the same spotbeam eliminated and the interference is only due to beam spillover in this example. The beam overlap factor for an orthogonal code system is given as follows;

$$b_{o_o}=J_1A_3+J_2A_4 \qquad (1\text{-}3)$$

3.3- Voice activity factor

CDMA with a significant percentage of voice users can reduce interference level by reducing the voice processing data rate during quiet voice periods. The low data rate voice processing during quiet periods reduces the transmit power, and produces reduction in the interference power.

4. Simulation results

In this section, simulation results of the performance of *DS-CDMA* systems, operating over a *LEO's* channel, with and without satellite diversity, in the presence of perfect and imperfect power control, are presented. We assume that all sequences within a given spotbeam are orthogonal; the Rician factor (*K)* is taken to be 7 and *10dB*, which are typical values in *LEO* channels. The processing gain is *PG=64*, defined as the number of chips per coded symbol, and perfect interleaving is considered.

In all cases, *BER* is plotted against the number of users per spotbeam. When just a single signal is available, the system performance is shown in fig 1. If we assume the standard deviation of the power control error is *1dB*, and we choose a *BER* of 10^{-3} as our goal, at *K=10dB* and *Eb/No*=8*dB*, then the system can accommodate about *M*= 24 simultaneous users per spotbeam.

In order to improve the capacity, suppose now that we have a system employing second order diversity. Performance results for such a scenario are shown in fig. 1. It is now seen more than 28 users can be accommodated with the same power control as before but at *Eb/No=6dB*. The diversity gain is more than 2.5*dB*. In fig.2, the performance without diversity at light shadowing, *K=7dB, PCE=1dB* and *Eb/No=9dB*, the system can support 20 users at $BER=10^{-3}$. However, with satellite diversity at *Eb/No=6dB* and the same previous conditions the system can support 22 users, and the diversity gain is approximately 3.5*dB*. In fig.3, the diversity gain at heavy shadowing, *K=0dB and PCE=2dB* is more than *6dB*.

For imperfect power control, the capacity of the system per spotbeam with *PCE=3dB* reduces by approximately 50% compared to perfect power control and the shadowed user is very sensitive to the *PCE* compared to the unshadowed user. For instance, Fig. (4) shows that when *K* equals 7 the capacity of the system per spotbeam at *PCE=3dB* equals 12 users, but for the perfect power control (*PCE=0*) antenna pattern the capacity of the system per spotbeam equals 24 users. Also Fig. (5) shows that when *K* = 3 and *PCE=3dB,* the capacity degrades significantly compared to perfect power control and the shadowing user is very sensitive to PCE.

For voice activity factor equals 0.65, the capacity of the system per spotbeam increases by approximately 60% compared to the system without voice activity. For instance, Fig. (6) shows that when *K* equals 10 the capacity of the system per spotbeam equals 32 users, but without voice activity factor the capacity of the system per spotbeam equals 19 users (considered *PCE=1dB* and uneven antenna pattern).

5. Conclusions

In this paper, a performance analysis has been carried out in terms of BER for the downlink. We find that the system performance is highly sensitive to the power control error, especially when the user is shadowed. Therefore, in order to increase the system capacity and improve system availability satellite diversity must be employed. Our results have shown that dual satellite diversity can achieve diversity gain up to 7dB. Further improvement of the system performance by approximately 60% can be achieved by taking into account the voice utilization factor.

Also, our results have shown that while *DS-CDMA* is a viable multiple accessing techniques for *LEOS* operations, the nature of the satellite channel makes it a less inviting choice than for a terrestrial system. In particular, if sophisticated channel coding techniques and sufficient interleaving can be employed, if dual satellite diversity is used, and if a power control system can be implemented so that the standard deviation of the power control error is less than or equal 1.5dB, *DS-CDMA* will result in good performance. If any of these design conditions are noticeably violated, significant degradation can result. Finally, reasonable *S-PCN* seems to be very well possible in rural, highway or open areas, whereas in urban areas the satellite will of course not be more than a complementary solution to the terrestrial systems.

References.

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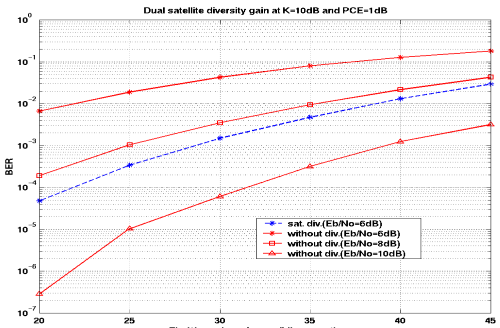

Fig.(1) number of users(M)per spotbeam

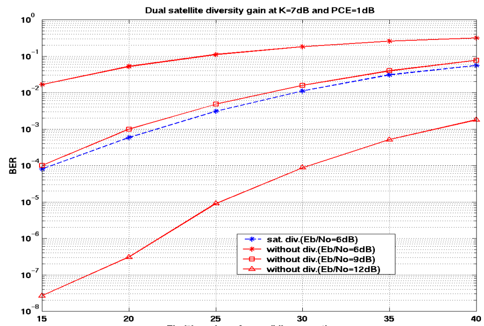

Fig.(2)number of users(M) per spotbeam

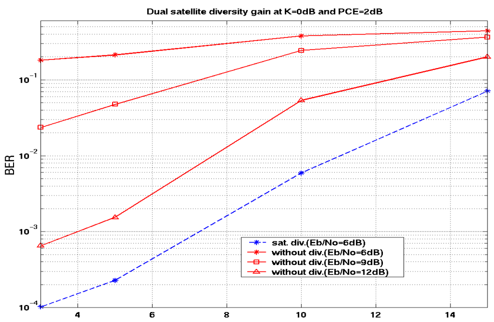

Fig.(3) number of users(M)per spotbeam

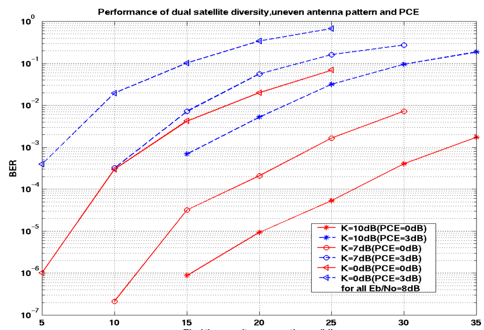

Fig.(4) capacity per spotbeam(M)

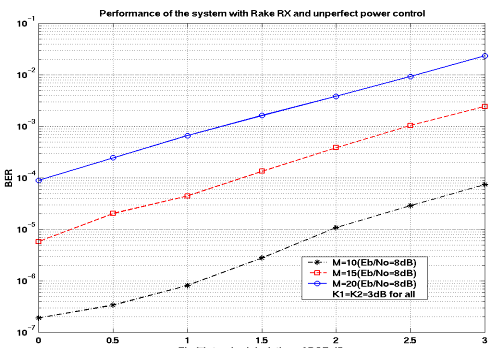

Fig.(5)standard deviation of PCE dB

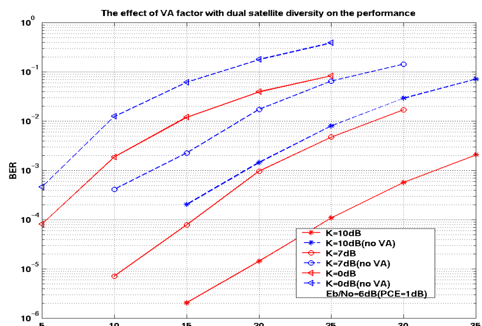

Fig.(6) capacity per spotbeam(M)