QPSK and BPSK Synchronous Sequence DS-CDMA Satellite Links

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Abstract: - DS-CDMA is the most practical techniques available in satellite spread spectrum multiple access schemes. This paper shows a software to calculate synchronous DS-CDMA satellite links, where the probability error and the maximum number of users, are used to evaluate its performance. Several non-orthogonal pseudorandom sequences generators are probed to get spread spectrum. The digital link budget is also employed to compare altitude orbits and features of terminal architectures.

Keywords: - Spread spectrum, CDMA, pseudorandom sequence, link budget, direct sequence, shift-register sequence generator.

1 Introduction

The basic architecture of the digital satellite communication systems has two important segments: the set of Earth stations (earth segment) and the satellites constellation (space segment), see Fig. 1.

We can distinguish the earth stations because their positions depend of Earth's rotation.

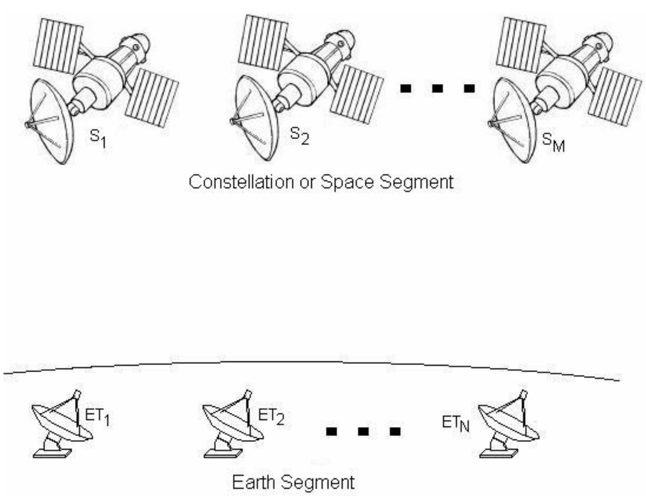

Fig. 1 Satellite Communication System.

In a communication system as we described before, it is necessary a multiple access scheme to allow us to chose an specific transmitter, Earth station or satellite (uplink or downlink). In this paper, we analyze an spread spectrum technique as a multiple access choice. Because, CDMA provides greater capacity than TDMA or FDMA, therefore, it represents a good candidate for the new generation mobile radio systems [9].

If each transmitter, Earth station or satellite has a unique code to spread his original signal bandwidth, then it is possible to select the origin of communication in any system's receiver. The transmitters codes can be generated employing simple sequential logic circuits, see Fig. 2. Where we have: N flip-flops in a shift register, N modulo-2 adders and b_i are binary coefficients.

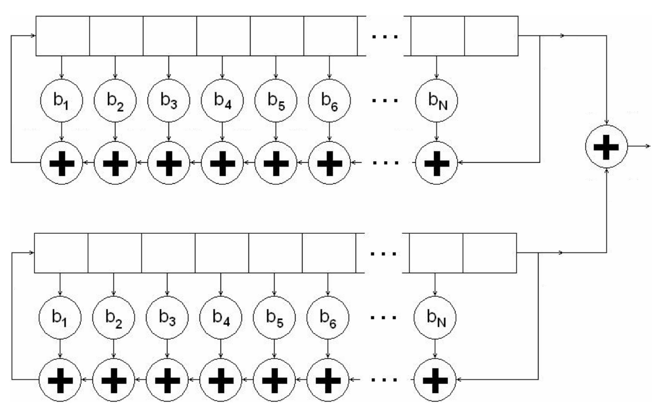

Fig. 2 Pseudorandom sequence generator

The initial state of the flip-flops must be different to zero. The output of the filter gives a large and almost unpredictable binary pseudorandom sequence. The configuration is the same as a *N*-step digital filter. The maximum period of the pseudorandom sequences *L* is determined by (1).

$$L = 2^N - 1 \qquad (1)$$

It is clear that maximum period implies that the filter will not contain the all-zero combination, this is the only exception in the general case.

Fig. 3 shows the autocorrelation coefficient for a Kasami large set sequence [6] [7].

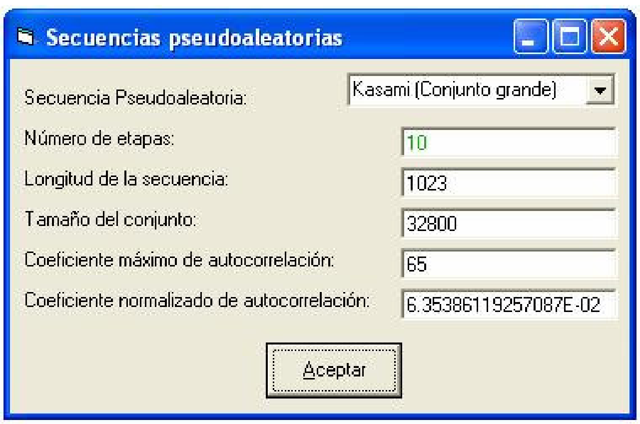

Fig 3. Calculation of normalized autocorrelation coefficient

2 Synchronous sequence CDMA

Although there are two main techniques to obtain spread spectrum as a multiple access scheme: frequency hopping and direct sequence; direct sequence is the only CDMA technique used in satellite communication systems. In this work we did not use frequency hopping CDMA.

We can generate DS CDMA if a bipolar pseudorandom sequence is multiplicated with the original narrowband signal sequence, the result is spread spectrum in the transmission media, the original signal is retrieve with identical operation in receiver. It is necessary to emphasize that the pseudorandom sequence must have an autocorrelation function $R_{uv}(\tau)$ almost zero, where u and v, are the original and τ-shift pseudorandom sequences respectively, and τ is not equal to zero.

Also, there are two alternatives in direct sequence CDMA: asynchronous and synchronous sequence. The synchronous DS-CDMA technique implies that all the pseudorandom sequence chips are equivalent to time bit duration. In this way, the maximum longitude of pseudorandom sequence takes an important value in the quality of service.

The cross–correlation value determines the signal to interference ratio degradation, it can be calculated, with (2).

$$R_{1m} = \sum_{j=1}^{N} p_j^{(1)} p_j^{(m)} \qquad (2)$$

Where R_{1m} is the cross-correlation value of sequences $\{p_j^{(1)}\}$ and $\{p_j^{(1)}\}$.

There are many filter options in pseudorandom sequence generation, we analyze the Gold, Bent and Kasami configurations and their variations, see Table 1, where we can compare de cross-correlation coefficient and the size of the sequence set. The set size indicates the maximum number of users in the system.

TABLE 1.
SHIFT-REGISTER CONFIGURATIONS

Family	*Set size*	$\lvert R_{uv,max} \rvert$
Gold Odd	2^m+1	$1+2^{(m+1)/2}$
Gold	2^m+1	$1+2^{(m+2)/2}$
Kasami (small set)	$2^{m/2}$	$1+2^{m/2}$
Kasami (large set)	$2^{m/2}(2^m+1)$	$1+2^{(m+2)/2}$
Bent	$2^{m/2}$	$1+2^{m/2}$

In practical systems, set size is specially important, because implies the maximum number of simultaneous users. Real sequence generators involve two shift-register configurations, where we can select the user employing the second register.

Other new procedures to generate pseudorandom sequences are based in a nonlinear dynamical system. The Average Interference Parameter (AIP) is employed to evaluate the systems and it has been shown that this technique gives an excellent signal to interference ratio. In this work, we preferred the common shift-register configuration, because it allows a fast code synchronization [8].

3 Digital link budget

The Digital Link Budget gives the power requirements and terminal equipment features to get an adequate probability error as a function of the application.

The probability error is limited by the digital modulation scheme, where the energy per bit to noise density ratio is very important. Equation (3) allows to calculate the energy per bit to noise density ratio.

$$\left(\frac{E_b}{N_0}\right) = \frac{R_p}{R_b}\left(\frac{C}{N}\right) \quad (3)$$

Where (E_b/N_o) is the energy per bit to noise density ratio, R_p is the chip rate, R_b is the bit rate, and (C/N) is the carrier to noise ratio.

The total carrier to noise ratio is determined by uplink and downlink carrier to noise ratios, and can be calculated (4).

$$\left(\frac{C}{N}\right)_T^{-1} = \left(\frac{C}{N}\right)_u^{-1} + \left(\frac{C}{N}\right)_d^{-1} + \left(\frac{C}{N}\right)_i^{-1} \quad (4)$$

Where $(C/N)_T$ is total carrier to noise ratio, $(C/N)_u$ is the uplink carrier to noise ratio, $(C/N)_d$ is the downlink carrier to noise ratio, and $(C/N)_i$ is the carrier to intermodulation noise ratio. Note that the total carrier to noise ratio is limited by the lowest carrier to noise ratio, [3] [4]

We can find the individual link carrier to noise ratio, as a result of the combination of power requirements and noise sources. In the uplink, we can use (5), where brackets indicate lineal to dB conversion.

$$\left[\frac{C}{N}\right]_u = \left[EIRP_u\right] - \left[L_{FSU}\right] + \left[\frac{G_u}{T_u}\right] - \left[kB_u\right] - \left[BO_i\right] - \left[L_u\right] \quad (5)$$

Where $EIRP_u$ is the Equivalent Isotropic Radiated Power required for satellite saturation, W; L_{FSU} are the uplink free space losses; G_u/T_u is the gain to noise temperature ratio of the satellite receiver, K^{-1}; kB_u is the Boltzmann constant and uplink noise bandwidth product, HzJ/K; BO_i is input backoff; and, L_u are the additional uplink losses, due to atmosphere, feed, polarisation and tracking losses, dB.

Fig. 4 shows a link budget example generated to evaluate DS-CDMA links, where BPSK or QPSK could be employed. The carrier to noise ratio is not high because we want to apply this calculation to mobile satellite radio systems, where the channel has several impairments.

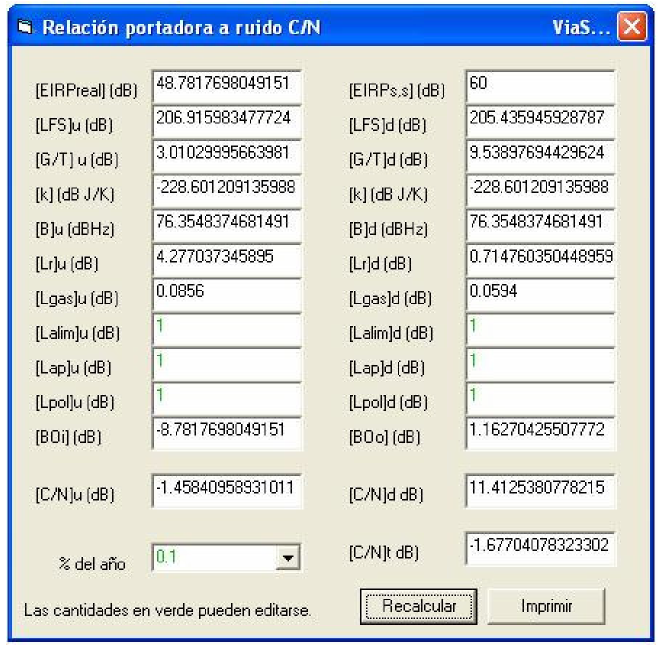

Fig. 4 Link.budget window obtained with ViaSat.

The downlink is determined similarly, see (6):

$$\left[\frac{C}{N}\right]_d = \left[EIRP_d\right] - \left[L_{FSD}\right] + \left[\frac{G_d}{T_d}\right] - \left[kB_d\right] - \left[BO_O\right] - \left[L_d\right] \quad (6)$$

Where $EIRP_d$ is the satellite saturation Equivalent Isotropic Radiated Power, W; L_{FSD} are the downlink free space losses; G_d/T_d is the gain to noise temperature ratio of the earth station receiver, K^{-1}; kB_u is the Boltzmann constant and downlink noise bandwidth product, HzJ/K; BO_o is output back off; and, L_d are the additional downlink losses, due to atmosphere, feed, polarization and tracking losses, dB.

Equation implicated in link budget were evaluated by ViaSat in several orbits configurations. This Software calculate in an arbitrary position of earth station, determined by their longitudes and latitudes.

4 System performance

In CDMA the (R_p/R_b) is also known as the processing gain, and it can improve de system performance, but increase the spread bandwidth. Then it is necessary to balance the maximum simultaneous users number in the channel, without spectrum waste [1].

The QPSK-BPSK DS-CDMA error probability can be computed by (7), [3].

$$P_b = Q\left[\sqrt{\frac{2}{n\rho_{\max}^2 + \left(E_b/N_0\right)^{-1}}}\right] \quad (7)$$

Where Q is the Q-Function, n is the simultaneous users number in the channel, ρ_{max} is the maximum of cross-correlation function, and (E_b/N_o) is the energy per bit to noise density ratio.

$$\rho_{1m} = \frac{1}{T_b}\sum_{j=1}^{L} p_j^{(1)} p_j^{(m)} \int_{jT_c}^{(j+1)T_c} g(t - jT_c)dt \quad (8)$$

We obtain (9) after integration.

$$\rho_{1m} = \frac{T_c}{T_b}\sum_{j=1}^{L} p_j^{(1)} p_j^{(m)} = \frac{R_{1m}}{L} \quad (9)$$

Where T_b is the bit duration, s; T_c is the chip duration, chips; L is the pseudorandom period, bits; $g(t)$ is the rectangular pulse function; and R_{1m} is the cross-correlation value.

The Q-function is defined in the following equation:

$$Q(z) = \frac{1}{\sqrt{2\pi}}\int_z^{\infty} e^{-x^2/2}dx \quad (10)$$

This equation is not exactly to evaluate, and we must approximate by iteration or simplified formulas. Equation (11) is well-known approximation of Q-function [3].

$$Q(z) = \left[\frac{1}{0.661z + 0.339\sqrt{z^2 + 5.51}}\right]\frac{e^{-z^2/2}}{\sqrt{2\pi}} \quad (11)$$

The autocorrelation coefficient is obtained with ViaSat for following shift-register configurations: Kasami (small and large set), Bent and Gold (normal and odd versions).

We used ViaSat to compute the probability of error in a synchronous DS-CDMA, see Fig 5.

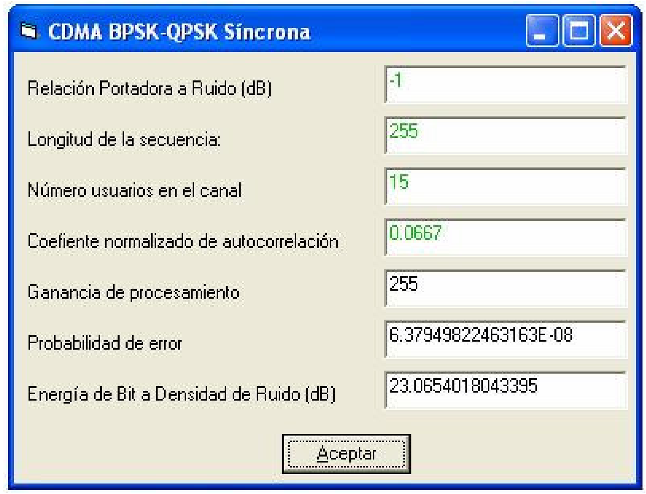

Fig. 5 Bit error rate calculation using ViaSat.

5 Results

The error probability for Kasami large set is shown in Fig. 6. Note that the error probability does not change significantly in a total [*C/N*] interval.

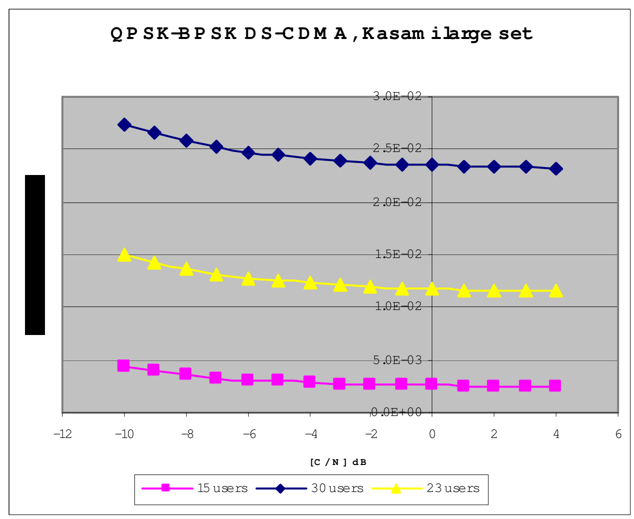

Fig. 6 Error probability vs total [C/N], with 15, 23 and 30 users.

We can compare the Kasami small set in the Fig. 7, where the number of simultaneous users is variable.

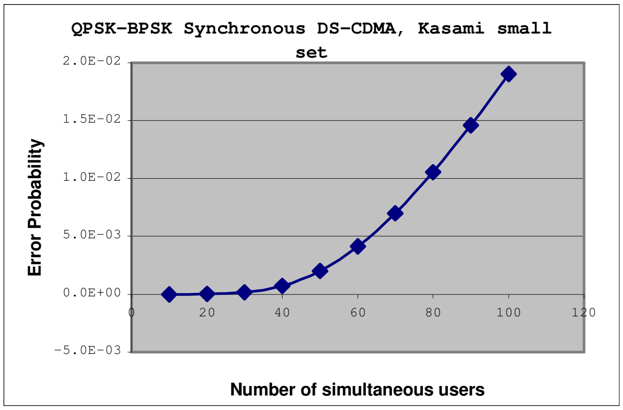

Fig. 7 Error probability vs number of users, for Kasami small set shift-register configuration.

In Fig. 8, we employed a 8-step shift-register configuration.

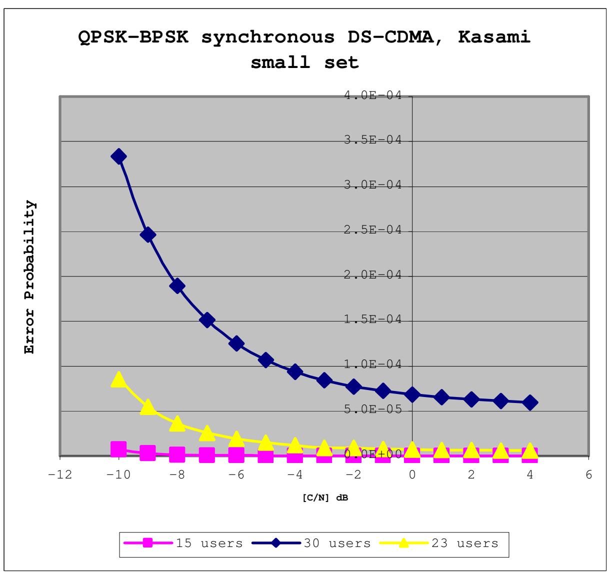

Fig. 8 Error probability vs total C/N, for Kasami small set shift-register configuration, where the number of simultaneous users are 15, 23 and 30 .

The results do not indicate a high number of simultaneous users, and in not recommendable to increase the processing gain, because the bandwidth increases too. The practical solution is to apply FDMA in combination with CDMA, but is necessary to take in consideration the input and output back-off, in [2] are described three methods to compensate the amplifier nonlinear response, but in this paper we employed the Shimbo formulas, to calculate the back off, where commercial TWT parameter were used.

The comparison of the shift-register configurations used in this paper is shown in Fig. 9.

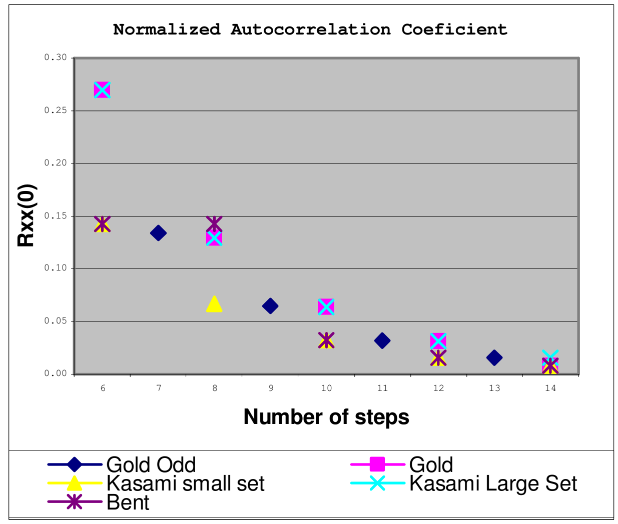

Fig. 9 Comparison of shift-register configuration.

6 Conclusions

The QPSK-BPSK synchronous DS-CDMA systems do not allow that a large number of users in a band limited single CDMA channel, but it is not practical a large number of CDMA channels, due to nonlinear impairments in the TWTA. After that it is necessary to employ orthogonal CDMA codes to increase the number of simultaneous users in the channel.

Actually, the synchronous DS-CDMA satellite systems are used where the number of users is not necessarily critical. The CDMA-RMA can be an alternative in comparison with DS-CDMA.

The link budget was computed with ViaSat software created by author, but does not include the cubic predistortion model. We are working to add this feature to ViaSat.

ViaSat is a preliminary software to teach digital satellite systems in the Metropolitan Autonomous University, where we enhance its features constantly.

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