Performance evaluation of VSAT MC-CDMA system using MUD in frequency selective environments

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Abstract: - In this paper the bit error rate performance of a satellite communication system based on Very Small Aperture Terminal (VSAT) technology and Multi-Carrier Code Division Multiple Access (MC-CDMA) scheme is investigated in frequency selective environments. The Multiple Access Interference (MAI) is a factor, which limits the capacity and performance of CDMA systems and in order to deal with this problem, the Multi-User Detection (MUD) techniques are proposed to compensate the MAI effect in the designed communication system. In this work, the uplink of VSAT MC-CDMA system is considered and the BER performance of Multiuser detection techniques will be compared to that of Single User Detection (SUD) schemes. The non-linear interference cancellation receivers are used in our simulations, because they have received a great deal of attention due to its advantages when compared with the other multi-user detectors. In this study we investigate different approaches concerning the combination of linear MMSE approach with non-linear interference cancellation schemes. The simulation results analysis of VSAT MC-CDMA system revealed that the receivers formed by the combination of linear MMSE approach and interference cancellation detectors can provide a considerable performance gain compared to interference cancellation schemes and SUD techniques. In addition, the combination of MMSE detector with non-linear interference cancellation schemes shows excellent performance even for high system loads.

Key-Words: - VSAT Network, MC-CDMA scheme, MUD techniques, SUD techniques, Uplink transmission.

1 Introduction

The field of satellite communications is still on a path of improvement, but in frequency selective environments the presence of multiple access interference in communication systems using CDMA technology hampers its progress and that can significantly degrades the system performance. This situation was the primary motivation for this work. In this paper we investigate the performance of different techniques of multi-user detection and single user detection which will be applied in satellite communication systems based on VSAT network and MC-CDMA scheme.

The main objective of this work is to evaluate the performance of a satellite communication system based on Very Small Aperture Terminal technology and MC-CDMA scheme in a multipath channel. The designed system is analyzed in the uplink transmission case in which transmitted signal is spread by orthogonal codes. Because of the frequency selectivity of the channel which causes the destruction of the orthogonality of the used codes, the multiple access interference has become present in the designed system. Therefore, to compensate the MAI effect different robust detection algorithms are proposed.

In this paper we investigate and compare the performance of various techniques of multiuser detector and single user detector for a satellite communication system based on VSAT technology and MC-CDMA schemes. In the single user detectors we proposed the performance evaluation of Zero Forcing (ZF), Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), and Minimum Mean Square Error (MMSE) in the VSAT MC-CDMA context. In the multi-user detectors the proposed techniques are capable of achieving excellent performance in the so-called full loading system. These techniques, namely, Successive Interference Cancellation (SIC), Parallel Interference Cancellation (PIC), Hybrid Interference Cancellation (HIC), and combinations of the linear MMSE approach with different non-linear detectors of interference cancellation (SIC, PIC, and HIC). To highlight the added value by the multi-user detectors, we began by performance evaluation of the designed system with introduction of single user detection techniques, and then we added the MUD algorithms in order to compare and analyze their performance in the designed VSAT MC-CDMA system.

The paper is structured as follows: In Section 2 the VSAT Network is briefly described with its configurations. The principle of MC-CDMA scheme is presented with modeling of designed system in Section 3. Sections 4 and 5, respectively, present the single user detection and multi-user detection techniques which are proposed in this study. In section 6 the simulation model and system specifications are presented. Performance evaluation of the envisaged system is presented in section 7, and conclusions are drawn in Section 8.

2 VSAT Network

Our study is based on VSAT network, because this network attracts the attention of large companies with subsidiaries implemented internationally. VSAT network has many advantages such as ease of installation, bidirectional communication, the reduced antenna size and configuration for any type of telecommunication services.

The term VSAT stands for Very Small Aperture Terminal and assumes the use of a (very) small diameter antenna (terminal) to receive and/or transmit radio signals (data) to/from a satellite [7].

The VSAT network can be physically configured in various ways called network topologies and there are two main network topologies:

- ***Meshed VSAT Network:*** In this network topology, VSAT terminals have the ability to communicate directly with one another without going through a central Hub. This topology requires relatively larger and more sophisticated VSAT terminals and indoor equipment which increases the start up costs. However, it is ideal for real time communications, such as telephony, among two or more locations in the same network [1][4].

- ***Star-Shaped VSAT Network:*** This is similar to a wheel's hub and spokes with several VSAT stations communicating through a central facility (the Hub) which regulates and controls communications. This is the more common network topology in use. The advantage of this topology is that the individual VSAT terminals can be kept relatively small (leading to lower start up costs) provided that a large dish (typically over 5 meters) is used at the Hub [12][13].

In conclusion, star configuration is imposed by power requirements resulting from the reduced size and hence the low cost of the VSAT earth station in conjunction with power limitation of the satellite. Meshed configuration is considered whenever such limitations do not hold, or are unacceptable. Meshed networks have the advantage of a reduced propagation delay (single hop delay is 0.25 sec instead of 0.5 sec for double hop) which is especially of interest for telephone service [2] [3].

3 MC-CDMA scheme

In this section the principle of MC-CDMA scheme is briefly described. The theoretical expressions of the transmitter and receiver models and decision statistic of the proposed system are also given.

Multi-carrier CDMA system is based on a combination of the CDMA scheme and orthogonal frequency division multiplexing (OFDM) signaling.

MC-CDMA transmitter spreads the original signal using a given spreading code in the frequency domain. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier.

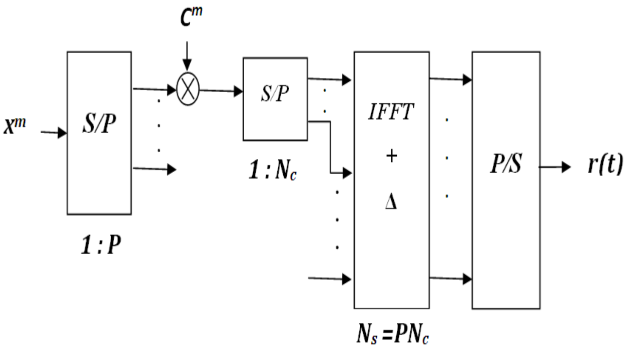

Fig. 1 MC-CDMA Transmitter

The figure 1 shows the MC-CDMA transmitter for the mth user. The input information sequence is first converted into P parallel data sequences, and then each Serial/Parallel converter output is multiplied with the spreading code with length L_C. All the data in total $N = P \times L_C$ (corresponding to the total number of subcarriers) are modulated in baseband by the inverse Fast Fourier transform (IFFT) and converted back into serial data. The guard interval Δ is inserted between symbols to avoid intersymbol interference, and finally the signal is transmitted.

Figure 2 shows the MC-CDMA receiver. It requires coherent detection for successful despreading operation and this causes the structure of MC-CDMA receiver to be very complicated. In figure, the k-subcarrier components (k=1,2,…Lc) corresponding to the received data y^m is first coherently detected with FFT and then multiplied with the gain G to combine the energy of the received signal scattered in the frequency domain [5]-[6].

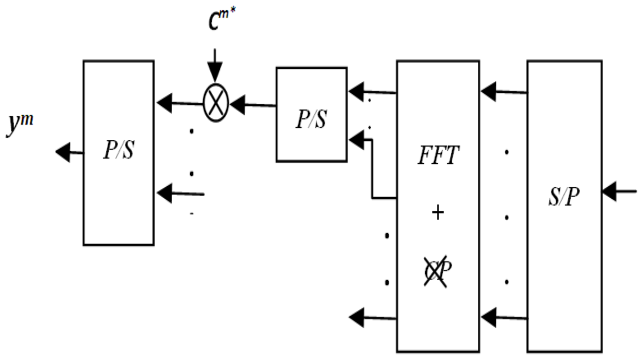

Fig. 2 MC-CDMA Receiver

3.1 Transmitter model of VSAT MC-CDMA

Transmitted signal $S(t)$ corresponding to the lth data bit of the mth user is defined by:

$$S(t) = \sqrt{\frac{2P_{\alpha,m}}{N}} \sum_{v=0}^{S-1} \sum_{l=-\infty}^{+\infty} \sum_{n=0}^{N-1} W_{\alpha,m}[n] b_{\alpha,m}[l] \cos\left(2\pi\left(f_c + \frac{n}{T_b}\right)t\right) C_\alpha[v] U_{T_b}(t - lT_b) \quad (1)$$

Where $P_{\alpha,m}$ is the power of data bit, $U_{T_b}(t - lT_b)$ is the rectangular pulse defined in the $[0, T_b]$. Every user has a spreading code $W_{\alpha,m}[n]$ with $n = 0,1, \dots, N-1$ and N is the length of the sequence chip. The same signature sequence chip is used to modulate each of the N carriers of the mth user. The maximum number of users in the system is M. Every VSAT has a signature $C_\alpha[v]$ with $v = 0,1, \dots, S-1$ and S is the length of the spreading code. α denote the number of VSATs with $\alpha = 1,2, \dots, K$ and K is the maximum number of VSATs.

3.2 Receiver model of VSAT MC-CDMA

The receiver signal of M active users in the VSAT-MC-CDMA system can be written as:

$$R(t)=\sum_{\alpha=1}^{K}\sum_{v=0}^{S-1}\sum_{m=0}^{M-1}\sum_{l=-\infty}^{+\infty}\sum_{n=0}^{N-1}\sqrt{\frac{2P_{\alpha,m}}{N}}\,\varphi_{\alpha,m,n}W_{\alpha,m}[n]b_{\alpha,m}[l]$$
$$\cos\left(2\pi\left(f_c+\frac{n}{T_b}\right)t+\psi_{\alpha,m,n}\right)C_\alpha[v]U_{T_b}(t-lT_b)+n(t)+\xi(t) \tag{2}$$

Where $\varphi_{\alpha,m,n}$ and $\psi_{\alpha,m,n}$ are respectively fading amplitude and phase shift. $n(t)$ is the additive white Gaussian noise (AWGN) with double sided power spectral density of $N_0/2$ and $\xi(t)$ is the inter-VSAT interference.

3.3 The Decision Statistic

The information bits $b_{\beta,j,n}$ received from a user specified ($m = j$) and VSAT ($\alpha = \beta$) will be used for this analysis. ($\alpha = \beta$) and ($m = j$) are the indices of despreaded information bits we want to retrieve. All other values of α ($\alpha \neq \beta$) and m ($m \neq j$) will be considered co-channel interference and inter-VSATs interference.

Assuming that users are synchronous in time, after demodulation and combination of sub-carrier signals, the decision variable is obtained as:

$$\mathcal{Y}_{\beta,j,l}=\frac{1}{T_b}\int_{lT_b}^{(l+1)T_b}R(t)\sum_{n=0}^{N-1}G_{\beta,j,n}W_{\beta,j}[n]$$
$$\cos\left(2\pi\left(f_c+\frac{n}{T_b}\right)t+\hat{\psi}_{\alpha,m,n}\right)C_\beta[v]dt \tag{3}$$

Where $G_{\beta,j,n}$ is the equalizing coefficient of the user j from the earth station β.

The decision variable consists of four components, the first term corresponds to the desired signal, the second term corresponds to the multiple access interference from other users, the third term corresponds to the noise and the last term represents the interference between VSATs.

$$\mathcal{Y}_{\beta,j,l}=\mathcal{D}+\mathcal{MAI}+\eta+\zeta \tag{4}$$

$\mathcal{D}$: Desired signal

$\mathcal{MAI}$: Co-channel interference

η : Noise

ζ : Inter-VSATs interference

Note that the absence of interference between symbols and the interference between carriers is ensured by the use of a guard interval longer than the delay spread of the channel impulse response.

Components of the decision variable can be written in the following form:

- Desired signal

$$\mathcal{D}=\frac{1}{2}\sqrt{\frac{2P_{\beta,j}}{N}}\sum_{l=-\infty}^{+\infty}\sum_{n=0}^{N-1}(S-1)\varphi_{\beta,j,n}\ b_{\beta,j}[l]G_{\beta,j,n} \tag{5}$$

- Co-channel interference

$$\mathcal{MAI}=\sum_{\substack{m=0\\m\neq j}}^{M-1}\sum_{l=-\infty}^{+\infty}\sum_{n=0}^{N-1}\frac{1}{2}\sqrt{\frac{2P_{\beta,m}}{N}}\varphi_{\beta,m,n}\ b_{\beta,m}[l]G_{\beta,j,n}$$
$$W_{\beta,m}[n]W_{\beta,j}[n]\cos(\psi_{\beta,j,n}-\psi_{\beta,m,n}) \tag{6}$$

- Noise

$$\eta=\sum_{v=0}^{S-1}\sum_{n=0}^{N-1}\frac{1}{T_b}\int_{lT_b}^{(l+1)T_b}n(t)G_{\beta,j,n}W_{\beta,j}[n]$$
$$C_\beta[v]\cos\left(2\pi\left(f_c+\frac{n}{T_b}\right)t+\psi_{\beta,j,n}\right)dt \tag{7}$$

- Inter-VSATs interference

$$\zeta=\sum_{\substack{\alpha=1\\\alpha\neq\beta}}^{K}\sum_{v=0}^{S-1}\sum_{m=0}^{M-1}\sum_{l=-\infty}^{+\infty}\sum_{n=0}^{N-1}\frac{1}{2}\sqrt{\frac{2P_{\alpha,m}}{N}}\,\varphi_{\alpha,m,n}W_{\alpha,m}[n]b_{\alpha,m}[l]$$
$$G_{\beta,j,n}C_\alpha[v]W_{\beta,j}[n]C_\beta[v]\cos\left(\psi_{\beta,j,n}-\psi_{\alpha,m,n}\right) \tag{8}$$

Generally speaking the jth user from the βth earth station, the SNIR can be expressed as:

$$SNIR=\frac{E\left[\left(\mathcal{Y}_{\beta,j}\middle|\vec{\varphi}_{\beta,j}\right)^2\right]}{\sigma\left(\mathcal{Y}_{\beta,j}\middle|\vec{\varphi}_{\beta,j}\right)} \tag{9}$$

Where $\vec{\varphi}_{\beta,j} = [\vec{\varphi}_{\beta,j,0}, \vec{\varphi}_{\beta,j,1}, \dots, \vec{\varphi}_{\beta,j,N-1}]$ is the vector of fading amplitudes of the user j from the earth station β. σ is variance.

Assume independent users and independent subcarriers,

$$E\left[\left(\mathcal{Y}_{\beta,j}\middle|\vec{\varphi}_{\beta,j}\right)^2\right] = \frac{1}{4}\frac{2P_{\beta,j}}{N}(S-1)^2\left(\sum_{n=0}^{N-1}\varphi_{\beta,j,n}G_{\beta,j,n}\right)^2 \quad (10)$$

$$\sigma\left(\mathcal{Y}_{\beta,j}\right) = \sigma(\eta) + \sigma(\mathcal{MAI}) + \sigma(\zeta) \quad (11)$$

$$\sigma\left(\mathcal{Y}_{\beta,j}\right) = E\left[(\eta)^2\right] + E\left[(\mathcal{MAI})^2\right] + E\left[(\zeta)^2\right] \quad (12)$$

The variance of the noise components is:

$$\sigma\left(\eta\middle|\vec{\varphi}_{\beta,j}\right) = \frac{N_0}{4T}\sum_{n=0}^{N-1}G^2{}_{\beta,j,n} \quad (13)$$

The variance of the MAI can be expressed as

$$\sigma\left(\mathcal{MAI}\middle|\vec{\varphi}_{\beta,j}\right) = \frac{1}{8}\sum_{\substack{m=0\\m\neq j}}^{M-1}\sum_{n=0}^{N-1}\frac{2P_{\beta,m}}{N}E\left[\varphi_{\beta,m,n}\right]G^2{}_{\beta,j,n} \quad (14)$$

The variance of the inter-VSAT interference is:

$$\sigma\left(\zeta\middle|\vec{\varphi}_{\beta,j}\right) = \frac{1}{8}\sum_{\substack{\alpha=1\\\alpha\neq\beta}}^{K}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\frac{2P_{\alpha,m}}{N}(S-1)^2 E\left[\varphi_{\alpha,m,n}\right]G^2{}_{\beta,j,n} \quad (15)$$

The following expression is the total variance of noise plus interferences of proposed system:

$$\begin{aligned}\sigma\left(\mathcal{Y}_{\beta,j}\middle|\vec{\varphi}_{\beta,j}\right) &= \frac{N_0}{4T}\sum_{n=0}^{N-1}G^2{}_{\beta,j,n}\\ &+\frac{1}{8}\sum_{\substack{m=0\\m\neq j}}^{M-1}\sum_{n=0}^{N-1}\frac{2P_{\beta,m}}{N}E\left[\varphi_{\beta,m,n}\right]G^2{}_{\beta,j,n} \quad (16)\\ &+\frac{1}{8}\sum_{\substack{\alpha=1\\\alpha\neq\beta}}^{K}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\frac{2P_{\alpha,m}}{N}(S-1)^2 E\left[\varphi_{\alpha,m,n}\right]G^2{}_{\beta,j,n}\end{aligned}$$

4 Single user detection techniques

In the MC-CDMA receiver, despreading is performed in the frequency domain after the FFT operation. The use of orthogonal codes such as Walsh-Hadamard codes in the synchronous system case, guarantees in a perfect channel the absence of multiple access interference. In contrast, during a transmission in a frequency selective channel, the orthogonality between codes is destroyed which creates an interference between users. The number of subcarriers should be chosen large enough to ensure the non-frequency selective channel on each of these subcarriers. The single user detection techniques consist of detecting the useful signal without taking into account the interference between users. Single-user detectors consider only the active user signal and the other users are considered as interferers.

After the FFT operation, the received signal is equalized in the frequency domain by multiplying each symbol received by an equalization coefficient $G_{\alpha,m,n}$ belonging to each sub-carrier, in order to compensate the attenuation and the phase shift introduced by the channel at the considered frequency. The different single-user detection techniques used in this study are the following:

4.1 Maximum Ratio Combining (MRC)

The MRC method is optimum relative to the error level in the case where a single user is active. It consists of multiplying each symbol by the conjugated complex response of the channel. The equalization coefficients of MRC detector are given by the following expression:

$$G_{\alpha,m,n} = H^*_{\alpha,m,n} \quad (17)$$

4.2 Equal Gain Combining (EGC)

This detection technique only corrects the phase distortion introduced by the channel. The equalization coefficients of EGC detector are given by the following expression:

$$G_{\alpha,m,n} = \frac{H^*_{\alpha,m,n}}{\left|H_{\alpha,m,n}\right|} \quad (18)$$

This technique also corrects partially the MAI introduced in a multi-user environment. However, it should be noted that the performance of this technique for a multi-carrier system, is unsatisfactory.

4.3 Zero Forcing (ZF)

The ZF technique makes it possible to eliminate integrally the interference between users by restoring orthogonality between the different spread codes. In this case, the equalization coefficients are equal to:

$$G_{\alpha,m,n} = \frac{1}{H_{\alpha,m,n}} \quad (19)$$

However, the main disadvantage of this method is that, for low amplitudes $H_{\alpha,m,n}$, the multiplication by an inverse function of the channel results in high amplification of noise, which rapidly degrades the error level.

4.4 Minimum Mean Square Error (MMSE)

The MMSE is a technique which provides a compromise between minimizing the multiple access interference term and maximizing the signal to noise ratio. It originated from the application of the Wiener filter. Calculating the equalization coefficient is designed to minimize the mean square error for each subcarrier between the transmitted signal and the equalized signal. This resolution leads to the coefficients expression, given by:

$$G_{\alpha,m,n} = \frac{H^*_{\alpha,m,n}}{\left|H_{\alpha,m,n}\right|^2 + \frac{1}{\gamma_c}} \quad (20)$$

The coefficient γ_c is calculated from the estimated SNR per subcarrier, inducing additional complexity.

5 Multi-user detection

In order to achieve better performance than those obtained by the single-user detection, multiuser detection is proposed. Indeed, this detection type already adopted by the terrestrial communications systems and has proven effective in reducing the interference impact on performance [11][17].

The advantage of multi-user detection compared to the single-user detection is the knowledge of the unwanted user codes for assessing as finely the interference present in the received signal. As a result, the data are better detected. In Multi-user detection techniques we are interested in evaluating the performance of designed VSAT MC-CDMA system with non-linear detection techniques and combination of these techniques with linear MMSE detector [11][16].

5.1 Interference cancellation schemes

The interference cancellation detectors seek to estimate the interference from other signals in order to subtracting the multi-user interference of the received signal. This method can be implemented in an iterative fashion, with several successive stages of detection. Different detection techniques can thus be combined in different stages. There are three main detectors in this group, namely, Successive Interference Cancellation detector (SIC), Parallel Interference Cancellation detector (PIC) and Hybrid Interference Cancellation detector (HIC).

5.2 Successive interference cancellation scheme

In each iteration of SIC receiver, the entire users signal is estimated and the signal with the largest power is regenerated and subtracted from the buffered received signal. The remaining signals are now re-estimated and a new largest user is selected and the process continues until all the users' signals have been recovered or the maximum allowable number of cancellations is reached. Successive interference cancellation receiver is shown in figure 3. The SIC receiver almost has an optimal performance and is quite reliable but number of iteration to cancel out all the MAI is directly proportional to the number of users. Hence the computation time is quite large [2][17].

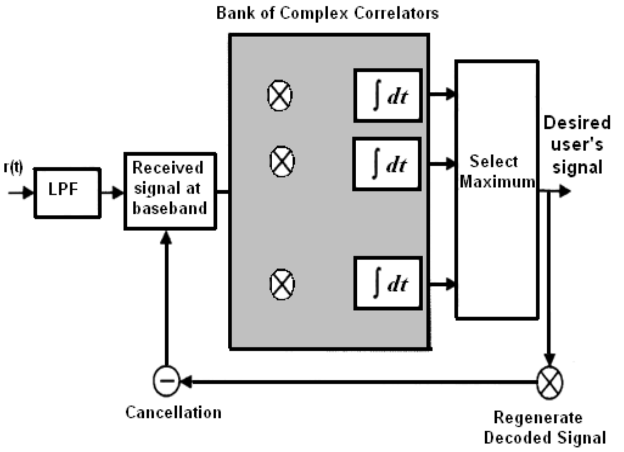

Fig.3. Block diagram of successive interference cancellation receiver

5.3 Parallel interference cancellation scheme

In contrast to the SIC receiver, the Parallel interference cancellation (PIC) receiver estimates and subtracts out all of the MA1 for each user in parallel. The basic block diagram of a single stage PIC receiver is shown in figure 4. The first block is that of a matched filter bank, which is used to arrive at the initial bit estimates for each user. These bits are then rescaled by the amplitude estimates and re-spread by the individual spreading codes to produce an estimate of the received signals of those users. The summer sums up all the estimated signals of various users and these are in turn subtracted from the total received signal. Hence a partially error free signal with less effect of MAI is obtained.

The advantage of the PIC receiver is that the process of cancellation is quite fast and there is no delay incorporated at the receiver. But the problem with this type of receiver is that the receiver complexity is quite large. Also the performance of the receiver is not reliable for there is a possibility of improper cancellation. The PIC receiver is faster than the SIC receiver, but at the same time, is more complex than the SIC receiver [8].

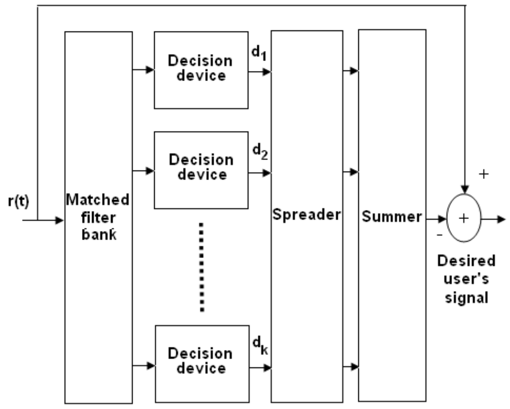

Fig.4. Block diagram of Parallel interference cancellation receiver

5.4 Hybrid interference cancellation scheme

Successive IC yields better performance with lot of processing time and parallel IC is superior to SIC in terms of computation time but is inferior in terms of BER. Hence a mix of SIC and PIC will yield an optimal result. The main idea behind hybrid IC is that instead of canceling all K users either in series or in parallel, they are cancelled partially in parallel and partially in series. The configuration for cancellation will be K-P-S, where K is the total number of users and the number cancelled in parallel and in series at each stage is denoted by P and S, respectively. The signals of the first P stronger users (out of K) are chosen to perform PIC between them. As a result of this action, the P most reliable users are chosen, and their signals reconstructed in order to subtract them from the buffered version of the received signal. Now, here 'P' signals are subtracted from the received signal. After that remaining K-P (i.e.S) users are arranged according to their strength and one by one, users are detected, subtracted and ultimately using this SIC all the users are detected. Obviously, HIC performs in an optimal way when compared with SIC and PIC. In figure 5 is shown the basic block diagram of hybrid interference cancellation receiver [9][10].

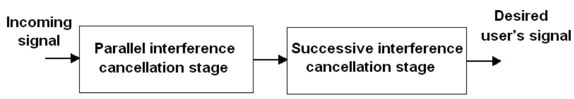

Fig.5. Block diagram of hybrid interference cancellation receiver

5.5 Combined detection

The combined detection results from the cascade of two multi-user detectors for example the combination of MMSE detector with interference cancellation detector (SIC or PIC or HIC). The first detector is used typically to initialize the second that is exploited to improve the overall performance of the detection.

The choice of detector types is related to requirements of receiver, from a performance, complexity and speed of processing standpoint. However, the first detector should fostering stability and discrimination between users. While the second detector uses its speed to converge, and insensitivity to the better to the elements of the receiver such as channel estimation and power control. Figure 6 provides an example of a combined detection structure of two users consisting MMSE and a PIC.

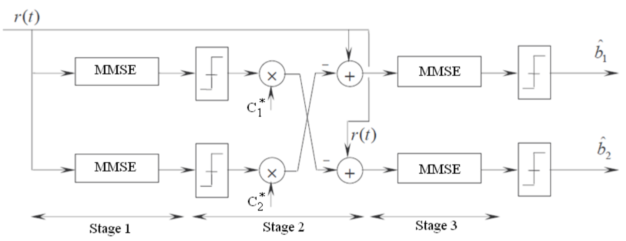

Fig.6. Block diagram of combined detection (MMSE/PIC)

6 Simulation model and System Specification

In this section we present the description of the simulation model and we illustrate the main characteristics of our proposed communication system. The figure 7 illustrates the overall simulation model. As we can see the binary input signal to the system is converted to symbol stream. The frequency domain spreading is done by using signature sequence of length 32 in the CDMA transmitter [14].

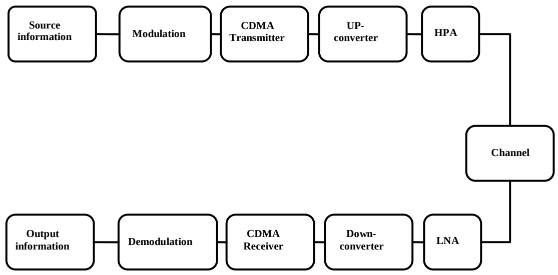

Fig 7. Overall Simulation Block Diagram

The up-converter is capable of outputting its carrier at the desired RF frequency. Signal is amplified with HPA before being transmitted through the transmission channel. LNA amplify very weak signals captured by the VSAT antenna. Down-converter converts the desired signal band to a convenient IF frequency for digitization. Despreading in the CDMA receiver is done before passing through the demodulator. The original binary data is recovered after passing through the decoder. In the VSAT MC-CDMA system we considered that the number of subcarriers is equal to the length of the signature sequence. The simulation parameters chosen for this study are the same parameters used in [15]. Thus the parameters that we used are as follows:

Table 1: General information

Satellite orbit radius	42242 km
Earth radius	6370 km
Distance from the VSAT to satellite	38054 km
Free space loss	206.1 dB
Speed of light, c	3.108 ms-1
Boltzmann’s constant	-228.6 dBJK-1 (=1.38 × 10−23J/K)

Table 2: VSAT Parameters

up-link frequency F_u	14.25 GHz
VSAT HPA output power P_{TxVSAT}	1 W
Antenna gain	42.84 dBi
Antenna diameter	1.2 m
EIRP	42.84 dBW
VSAT latitude	45.5° N
VSAT longitude	9.5° E
Elevation angle	37.56°
Azimuth angle	183.5°

Table 3: Satellite Parameters

Satellite figure of merit $(G/T)_{SL}$	1 dB/K
satellite receiver effective input noise temperature	500 K
Satellite antenna noise temperature	290 K
uplink system noise temperature	790 K
Power Flux density ϕ	-119.22 dBW/m^2
Transponder bandwidth	54 MHz
Satellite antenna gain	31 dBi
Sub-satellite point longitude	7° E
C/N_0 in up-link	66.34 dBHz

Table 4: MC-CDMA Parameters

S/P converter output	16
Symbol duration after S/P conversion	15,625 μs
symbol duration T_s	0,9765 μs
Guard interval Δ (20 % de T_s)	0,1953 μs
Number of sub-carriers	32
Number of carriers	512
Length of Walsh codes	32
Length of PN sequences	32

7 Results and discussion

In order to investigate the performance of VSAT MC-CDMA system with different techniques of MUD and SUD, a performance comparison is conducted in a multi-paths environment. The multistage of interference cancellation schemes is terminated when there is no significant change from the previous stage. Therefore, in our simulations we considered only the third stage because the BER curves of stages 3 and 4 are almost identical. In the designed MC-CDMA system, the orthogonal Walsh codes are used to separate users. To analyze our VSAT MC-CDMA system when the multiple access interference is severe, we performed our simulations in full loading case. All of the simulations carried in this work are done with the assumption that all active users have equal power. Therefore, the performance results of VSAT MC-CDMA system are obtained for a number of sub-carriers equals the number of chips of the spreading code, the maximum number of users is fixed at 32 (full loading) and the code length of spreading code is 32 chips. In this study, the maximum number of earth stations is fixed at eight. Indeed, 32 users are distributed over eight earth stations. However, all users in the VSAT network are uniformly distributed between the ground stations.

7.1 VSAT MC-CDMA system with SUD schemes

The simulation results of VSAT MC-CDMA system with various single user detection techniques (EGC, MRC, ZF, and MMSE) are depicted in figure 8 in the full loading case. It can be noticed that the MMSE detector outperforms the other single user detection techniques preventing excessive noise amplification for low energy per bit to noise power spectral density ratios (E_b/N_0) while restoring the orthogonality among users for large E_b/N_0. The ZF scheme recovered the orthogonality between the different signals and avoids the inter-user interference, but at the cost of a significant amplification of noise, especially for low E_b/N_0. In figure 8, we can observe that for a bit error rate approximate to 10^{-4} the MMSE detector provides an equalisation gain of approximately 3.5 dB compared to ZF detector.

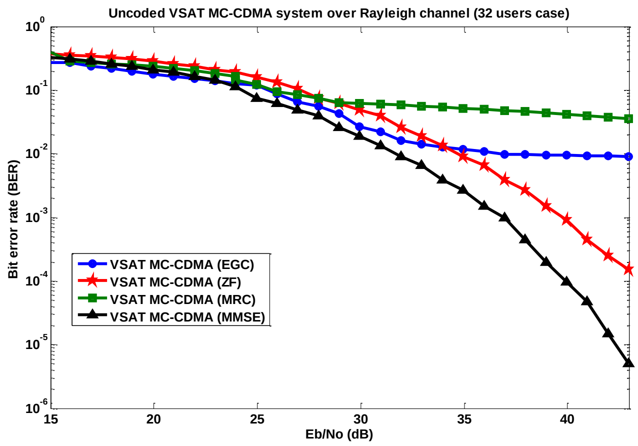

Fig.8. Performance of SUD schemes in VSAT MC-CDMA

In addition, the detectors ZF and MMSE use a linear channel equalisation and they are more sensitive to inaccurate channel estimation than diversity combining detectors such as EGC. Moreover the worst performance is achieved with the MRC technique that accentuates the inter-user interference. In order to obtain better performance in term of bit error rate, the Multi-user Detection schemes can be carried out.

7.2 VSAT MC-CDMA system with MUD schemes

Figure 9 shows the bit error rate performance of VSAT MC-CDMA system with the three non-linear interference cancellation receivers (SIC, PIC, and HIC). From the figure, it is obvious that for different interference cancellation schemes the bit error rate performance achieves up to 10^{-5}. It can also be noted that for a BER = 10^{-5} the E_b/N_0 is roughly equal to 36.5 dB for the SIC detector, 38.5 dB for HIC detector, 40 dB for PIC detector, and 42.5 for MMSE detector. Based on the results of the figure 9 we find that the SIC technique improves the bit error rate performance of the designed VSAT MC-CDMA system to a very good scale. The downside of the successive interference cancellation scheme is that it introduces delay in the functioning of the system.

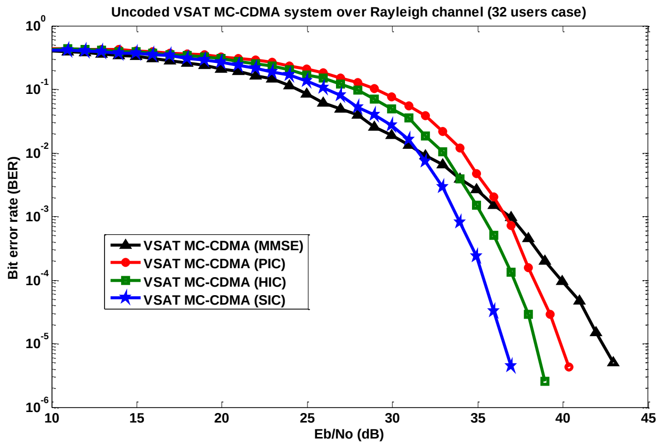

Fig.9. Performance of MUD schemes in VSAT MC-CDMA

In contrast, the PIC technique improves the BER performance of the VSAT MC-CDMA system but not to the scale of SIC scheme but does not introduce much delay in the functioning of the system. The HIC receiver provides a bit error rate performance which is better than the PIC scheme but not to the scale of SIC scheme. The HIC presents a good tradeoff between SIC and PIC schemes.

Figure 10 illustrates the bit error rate performance of different proposed combinations between linear MMSE approach and non-linear interference cancellation schemes.

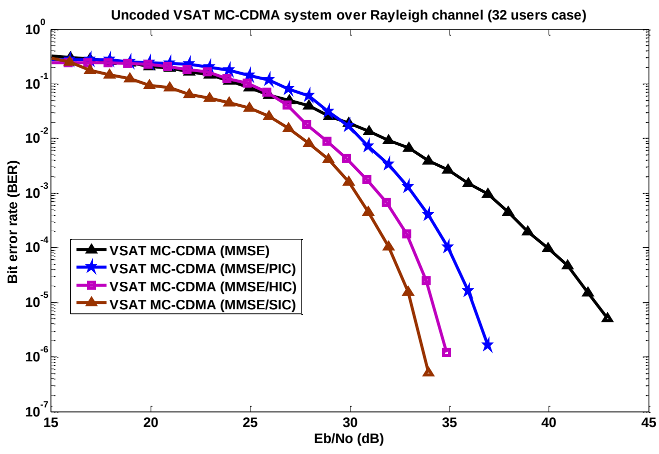

Fig.10. Performance of combined MMSE/IC schemes in VSAT MC-CDMA

From the figure 10 we can notice that for a $BER = 10^{-5}$ the E_b/N_0 is roughly equal to 33 dB for the MMSE/SIC receiver, 34 dB for MMSE/HIC receiver, and 36 dB for MMSE/PIC receiver.On the basis of performance results of the above figure we can also find that the VSAT MC-CDMA system with the combined MMSE/SIC scheme provides the best performance in term of bit error rate. The BER performance of the rest of the systems is in the order of VSAT MC-CDMA system with the combined MMSE/HIC scheme, VSAT MC-CDMA system with MMSE/PIC scheme and VSAT MC-CDMA system with MMSE scheme.

8 Conclusion

The performance evaluation of VSAT MC-CDMA system with different schemes of MUD and SUD over Rayleigh channel has been investigated in uplink case. From the simulation results it was found that the VSAT MC-CDMA system with interference cancellation receivers performs well when compared with VSAT MC-CDMA system using single user receivers. Considering all the interference cancellation schemes, the performance of successive interference cancellation receiver is better.

The detectors formed by the combination of interference cancellation receivers and non-linear MMSE approach provide good results compared to interference cancellation receivers. In VSAT MC-CDMA system, the bit error rate performance of MMSE/SIC receiver has been better compared to MMES/HIC and MMSE/SIC receivers.

In conclusion, the comparison between different receivers based on combination of MMSE and interference cancellation schemes. It is very evident that VSAT MC-CDMA system with MMSE/SIC receiver provides the best BER performance. But, this combined receiver consumes much time. Accordingly, the MMSE/PIC receiver consumes less time and provides a poor performance. The MMSE/HIC is an optimal receiver which represents a good trade-off between the both receivers MMSE/SIC and MMSE/PIC.

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