A Study of Implementation of Multiuser Detection in Asynchronous Multi-Beam Communications

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Abstract

This paper deals with multi-user detection techniques in asynchronous multibeam satellite communications. The proposed solutions are based on successive interference cancellation architecture (SIC) and channel decoding algorithms. The aim of these detection methods is to reduce the effect of cochannel interference due to co-frequency access, and consequently, improves the capacity of the mulitbeam communications systems, by improving frequency reuse. Channel estimation allows the determination of interference coefficients, which helps their effects compensation. The developed multiuser detections techniques are iterative. Therefore, detection quality is improved from a stage to another. Moreover, a signals combining method, which is integrated into these detection solutions, enhances their capability. The proposed solutions are evaluated through computer simulations, where an asynchronous multibeam satellite link is considered over an AWGN channel. The obtained simulation results showed the robustness of these multi-user detection techniques.

Keywords: - *Multi-Beam System, Co-Channel Interference, SIC, Channel Decoding, Signals Combining.*

1. INTRODUCTION

With the explosive evolution of information and communications technologies, mobility and flexibility of terminals become a necessity for several kinds of services. Wireless systems constitute a basic solution to satisfy these needs. In fact, they guarantee wireless and mobile communications for users independently of their localities. Thus, wireless communications solved some deficiencies of wired solutions. These contributions are mainly due to the transmission support; the atmosphere. The last allows data transmission everywhere; but an efficient physical resource sharing between users is necessary. Moreover, wireless transmissions are subject of several problems such as fading, noise, interference, multipath etc… These natural problems are dealt with robust signal processing techniques at the receivers. As an example of wireless systems, satellite stations are good solutions which provide wide coverage and different communications services. These systems can guarantee network coverage in isolated places, where wired infrastructures and terrestrial wireless stations are difficult to install. Satellite systems offer also some specific services such as broadcasting, localization, tracking etc. Wireless channel is a common transmission support, which is shared between several simultaneous communications. Thus, efficient access and use of this communication mean is of great importance. Frequency is the main characteristic of wireless channels. Then, optimal division and reuse of this physical resource is needed to design high capacity communications systems. For wireless terrestrial networks, adjacent transceiver stations use different frequencies. In satellite systems, multibeam technology is a good solution for frequency reuse. This method forms at the satellite receiver a throng of narrow beams instead of a single wide beam. Each beam is defined by it carrier frequency.

Thus, these different beams cover terrestrial zones with a co-frequency reuse for no adjacent cells. As a result, the capacity of the satellite system increases at the cost of co-channel interferences (CCI) and multiple access interference (MAI). The problems, which are due to these interferences and the noise, will be dealt by the receiver. In this paper, we have developed some multi-user detection techniques for asynchronous multibeam systems. The aim of these solutions is to deal with co-channel interference, and provide an efficient frequency reuse. The proposed solutions are based on channel decoding, channel estimation, and interference cancellation, which operate in iterative processes. Due to asynchronous access of users to the system, propagation delay estimation task is needed as a first processed operation by the receiver. The developed techniques take advantage from the spatial diversity due to satellite antenna array. Thus, a signals combining solution, integrated in the multi-user detection methods, allows signal to noise ratio (SNR) improvement which leads to better detection quality. The remainder of this paper is organized as follows.

2. SIGNAL MODEL

We consider the asynchronous uplink of a multibeam satellite system. K active users share a co-frequency channel and send their signals to satellite antenna array. The K users belong to different cells which are covered by co-frequency beams. Users in the same cell adopt a TDMA access to physical resources. Thus, co-channel interferences are due to same frequency reuse. Mathematically, we represent the kth signal by:

$$r_k(t) = a_k e^{j\varphi_k} x_k(t) \quad (1)$$

Where, k a and ϕ k are the amplitude of the signal and its carrier phase, and x (t) k is given by:

$$x_k(t) = \sum_{i=0}^{N-1} x_k[i] g\left(t - iT - \tau_k\right) \quad (2)$$

With, x [i], i = ..0 N −1 k is a sequence of N QPSK symbols, g(t)is the emitter filter waveform, T is the symbol temporal duration and k τ is the propagation delay of the kth signal. For simplicity and without loss of generality, we assume an ordering on the time delays such that: . τ 1 ≤ τ 2 ≤K≤ τ K < T We suppose that the propagation delays are multiple of T Ns / ; the sampling period. Thus, Ns represents the sampling factor or the number of samples taken by symbol during. The sequence of N symbols, which are convolutional coded and interleaved before transmission, is divided into N p pilot symbols and Ni information symbols. This signal, expressed in (2), is received by the L radiating components of the antenna array, (see figure 1). Thus, if we generalize for the K users, the signal received by the th l element of the antenna can be expressed by:

$$s_l(t) = \sum_{k=1}^{K} d_k^{(l)} r_k(t) + n_l(t) \quad (3)$$

With, (l) dk is the l th coefficient of the steering vector k d of the kth received signal, and n (t) l is a Gaussian noise, added to the composite signal received by the l th antenna component. To arrange the L signals received by the antenna array sensors, we define the signal vector s t)(by: [ ] T L s(t) s (t),s (t), ,s (t) = 1 2 K . Where, T (.) denotes the transpose operator. Thus, generalization of equation (3) for the L components of the antenna gives:

$$s(t) = \sum_{k=1}^{K} d_k r_k(t) + n(t) \quad (4)$$

Where, k d , as it is mentioned above, is the column vector of length L which contains information about the arrival direction of the kth signal [25], and T L n(t) [n (t), , n (t)] = 1 K is the additive noise vector at the L radiating elements outputs. We define the direction of arrival (DOA) matrix of the K beams by: [, ,] 1 K D = d K d , and the vector of received signals: T K r(t) [r (t), ,r (t)] = 1 K . Thus, equation (4) can be rewritten as follows:

$$s(t) = Dr(t) + n(t) \quad (5)$$

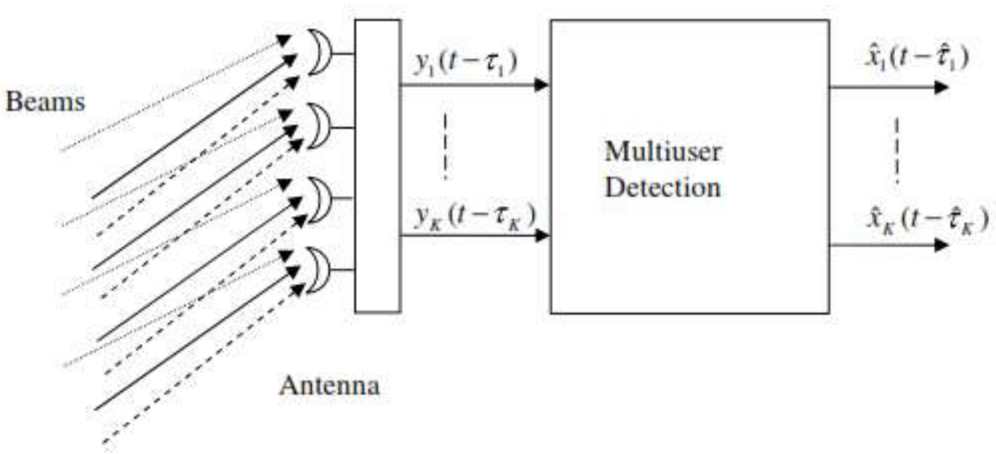

Figure 1. Reception model.

At the receiver, beam forming operation maximizes the energy of the useful signal by steering the antenna array in the DOA of this beam [25]. Thereafter, to form the kth beam, the treatment consists of taking a linear combination of the signals at the antenna elements outputs. The obtained signal for the kth beam is given by:

$$y_k(t) = v_k^{\ T}\ s(t) \qquad (6)$$

With, k v is a column vector which contains the L coefficients of the kth beam forming. Generalization of the expression (6) for the K active users in the system gives:

$$y(t) = Vs(t) \qquad (7)$$

With, [ ] T K y(t) y (t), y (t), , y (t) = 1 2 K and [ ] T K V v , v , , v = 1 2 K . Using (5), equation (7) becomes:

$$y(t) = VDr(t) + Vn(t) = Wr(t) + Vn(t) \qquad (8)$$

We define the diagonal matrix of the K signals complex amplitudes by: ([, ,]) 1 1 j K K j A diag a e a e ϕ K ϕ = . With diag(.) denotes the matrix diagonal operator. Using the expression of r t)(in (1), equation (8) can be rewritten also:

$$y(t) = WAx(t) + Vn(t) \qquad (9)$$

Where, T K x(t) [x (t), , x (t)] = 1 K By introducing the channel matrix H = WA , and the noise vector z t)(=Vn t)(, equation (9) becomes:

$$y(t) = WAx(t) + Vn(t) \qquad (10)$$

3. MULTI-USER DETECTION

The proposed multi-user detection techniques are composed of some functional blocks which operate the following jobs: propagation delay estimation, phase estimation, channel decoding, channel estimation, interference cancellation and signals combining. These operations are executed successively. In each block of the receiver, signals users are also dealt successively. Some of these operations are processed iteratively in some stages and the others are dealt only at the beginning of algorithms running.

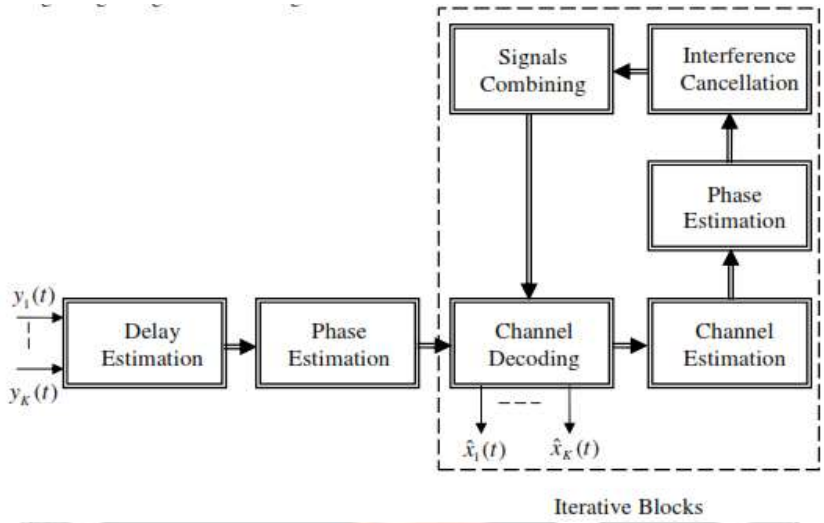

Figure 2. Receiver architecture.

Delay Estimation

The first operation to be dealt is the propagation delays estimation. The results of this operation are then used by the following receiver blocks. Thus, the performance of the multi-user detection is strongly influenced by the delays estimation performances. In each processing operation of the receiver, the asynchronous character of the signals is not modified but taken into account. The propagation delay estimation technique is based on signals correlation, and it uses the pilot symbols. For the kth signal, estimation of its propagation delay can be expressed by

$$\hat{\tau}_k = \arg Max\left(\left|\sum_{i=1}^{N_s\times N_p}\mathrm{Re}\left(y_k(i).P_k(i)^*\right)\right| + \left|\sum_{i=1}^{N_s\times N_p}\mathrm{Im}\left(y_k(i).P_k(i)^*\right)\right|\right) \quad (11)$$

Where, Re(.) and Im(.) denote the real part and imaginary part of a complex number respectively, and * (.) denotes the conjugate operator of complex number. N p is the pilot symbols number.

Phase Estimation

From figure 3, we note that the receiver contains two phase estimation blocks. In fact, these two operations are done differently. The first is an initialisation of the iterative algorithm. It is needed to compensate the phase effects before decoding algorithms processing. In the first stage of the multi-user detection techniques, an initial phase estimation of the kth signal is given by:

$$\hat{\varphi}_k = ang\left(\sum_{N_p} y_k(j)\tilde{P}_k(j)^*\right) \quad (*12)$$

Where, Pk ~ is a Ns × N p length column vector. It is derived from the pilot sequence vector Pk as follows: [ ] T Pk Pk Pk Pk Np Pk N p 1( ),..,),1(, ( ),.., ( ) ~ = K , with, Pk is the vector of kth user training sequence which consists of N p pilot symbols. And, ang(.) denotes the angle of a complex number operator. The second phase estimation block, which is included in the iterative part of the algorithms, is performed after channel coefficients estimation. This iterative operation can be expressed, for the kth signal at the nth stage, as:

$$\hat{\varphi}_k^{(n)} = ang\left(\hat{h}_{k,k}^{(n)}\right) \quad (13)$$

With, ( ) , ˆ n hk k is the (k, k)th channel matrix estimation at the nth iteration.

Channel Decoding

Before channel decoding, the signals phases are compensated with use of phases estimations. This operation consists to multiply the symbols samples by the quantities ( ) ˆ n k j e − ϕ for the K users respectively. We have implemented two different decoding methods for the convolutional channel coding. They are the Viterbi algorithm and the BCJR one. The second technique needs SNR knowledge. Thus, SNR estimation operation, which is not presented in the above receiver architecture, is necessary. This task is explained in the following paragraph.

SNR estimation

The SNR estimation is computed in each iteration before BCJR or MAP (Maximum a Posteriori) decoding operation. It is based on the BCJR algorithm itself. That solution provides an estimation of the signal to noise ratio by minimizing the bit error rate between the pilot symbols and the decoded samples which correspond to the transmission of that pilot sequence. Thus, SNR estimation can be described by:

$$\hat{SNR} = \arg\left(\min_{snr\in[snr_{min},\, snr_{max}]}(BER)\right) \quad (14)$$

Channel Estimation

The channel estimation technique allows the determination of CCI coefficients in order to compensate their effect in interference cancellation block. These coefficients, which are the channel matrix H elements, are estimated iteratively. In each stage, they are updated, with use of estimated and pilot symbols. Channel coefficients estimation of the kth signal at the nth iteration can be expressed by the following equation:

$$\hat{h}_{k,l}^{(n)} = \frac{1}{2\times N_s(N+1)} \sum_{j=1}^{N_s(N+1)} y_k(j)\hat{x}_l^{(n)}(j) \quad (15)$$

Where, - ( ) , ˆ n hk l is the estimation of interference coefficient of signal l on signal k at nth iteration, or the (k,l) th element estimation of the matrix H at the at the nth iteration. - The value 2 in the denominator is to compensate the effect of the square of the QPSK symbols modulus on the channel coefficients estimation. - ˆ ( ) ( ) x j n l is the estimation of the jth symbol of user l at the nth iteration.

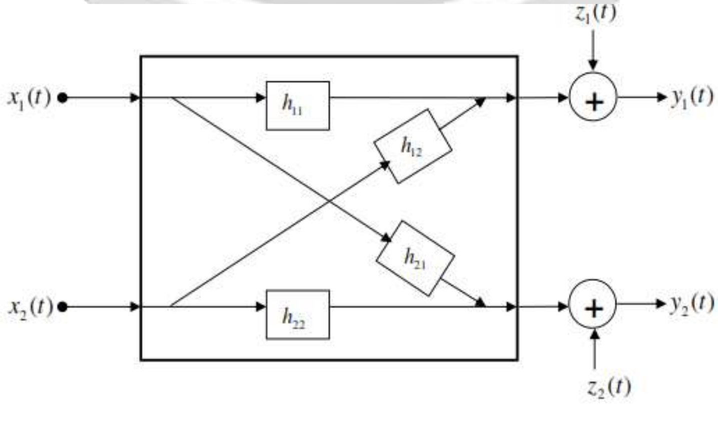

Figure 3. CCI Channel Model for K=2.

Interference Cancellation

The successive interference cancellation block ensures the CCI suppression from the K beams. Thus, co-frequency signals are dealt successively in each iteration. Symbols of interfering signals are extracted from the useful signal with use of the appropriate estimated channel coefficients, and taking into account of signals propagation delays. Thus, interference cancellation from the jth sample of kth signal at the nth iteration is expressed by:

$$\chi_k^{(n)}(j) = \sum_{\substack{k'=1 \\ k' \neq k}}^{K} \left(\hat{h}_{k'}^{(n-1)}(k)^{*} \left(y_{k'}(j) - \sum_{\substack{k''=1 \\ k'' \neq k'}}^{K} \hat{h}_{k''}^{(n-1)}(k'') \hat{x}_{k''}^{(n-1)}(j) \right) \right)$$

(17)]

$$\tilde{y}_k^{(n)}(j) = y_k^{(n)}(j) + \chi_k^{(n)}(j)$$

(18)

Thereafter, at the nth iteration, for the jth symbol of the kth signal, the decoder computes the quantity ( ) ~( ) y j n k .

4. CONCLUSIONS

In this paper, we have developed and evaluated through computer simulations some multi-user detection solutions for asynchronous multibeam systems. The proposed techniques are based on successive interference cancellation architectures which implement channel decoding and estimation methods. We integrated two convolutional decoding algorithms. The Viterbi technique and the BCJR one. Both multi-user detection techniques showed good performances under noisy and CCI situation. Moreover, the quality of symbols detection is improved from a stage to another. The solution, which implements MAP decoding, gave better results compared to the detection technique employing Viterbi decoding algorithm. But, it introduced more processing complexity in the receiver due to probabilities calculation, in addition to the SNR estimation block, which is needed for MAP decoding. Thus, the multi-user solution, which integrates Viterbi algorithm, is faster in execution, than the other. As we dealt with asynchronous communications, estimation of propagation delays operation was of significant importance. Its good performances helped enormously detection techniques processing. Through the simulations results, we can conclude the importance of the signals combining technique. This operation allowed SNR improvement of the useful signal, which leads to a better quality of detection, and therefore, a possible reduction of the stages number. As a future work, it will be interesting to deal with multi-user detection techniques in multibeam communications under an asynchronous multipath channel.

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