An Inter-Group Swapping Based Resource Scheduling Scheme for Quasi-Single Frequency Multi-beam Mobile Satellite System

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Abstract. A resource scheduling scheme is proposed in this paper for multi-beam satellite system to eliminate downlink interference as well as to overcome the noise amplification problem caused by Tomlinson-Hiroshima preceding. Firstly, to analyze the noise amplification problem, Tomlinson-Hiroshima preceding (THP) is discussed. Secondly, an inter-group swapping based resource scheduling scheme is proposed to according to the principle of minimizing the maximum noise amplification factor of the same frequency users. Finally, simulations are executed to validate the proposed scheme, which suggest that compared to no-swapping scheme, the proposed scheme can successfully reduce the ratio of low SINR users and improve the minimum signal to interference and noise ratio(SINR).

1. Introduction

With the development of wireless communication technology and diversified wireless communication applications, the Mobile Satellite System (MSS) is becoming more and more popular between research community and industry due to its wide coverage, large capacity, flexible networking and cost independent of distance. In recent years, based on the development of land mobile communication technology, OFDM-based multi-beam satellite mobile communication system has been widely studied and applied.

Usually, the multi-beam satellite system can suppress the inter-beam interference (IBI) [1] by using the traditional frequency-division reuse scheme, which is divided into three-color, four-color and seven-color reuse. But the spectral efficiency is low by using this method. Most frequency bands of the quasi single frequency network are the same frequency reuse among the beams, and a few of the frequency points are reused among the beams, which can effectively improve the spectrum efficiency of the system. In quasi single frequency networked satellite systems, co-channel interference between beams can be effectively controlled or even eliminated by using specific interference cancellation techniques at the transmitter or the receiver, or both [2]. In [4], a method is proposed to eliminate inter-beam interference by using iterations at the receiver, but its drawback is that the design complexity and computational complexity of the receiver are dramatically increased. THP is a simple and effective interference cancellation technique for terrestrial systems. Aiming at the adaptability requirement of THP in quasi single frequency network satellite communication, his paper designs a resource scheduling scheme.
2. System Model

In this paper, a multi-beam satellite mobile communication downlink system model based on quasi single frequency network is proposed. In the downlink of the quasi single frequency network system, most frequency points adopt the same frequency reuse mode among the beams, and for the same frequency reuse users, interference cancellation with precoding is performed at the transmitter side. In the same frequency division reuse mode, the users are grouped in a certain resource scheduling mode, and the users that are pre-encoded at the same time are assigned to the same user group for joint precoding. At the same time, several extra frequency points are reserved for users who do not derive a performance gain from the precoding interference cancellation. These frequency points take a three-color frequency reuse pattern among the beams and not participate in the precoding interference pre-elimination, as is shown in Figure 1.

At this time, system frequency reuse factor $FR_{sys}$ is given by:

$$FR_{sys} = \frac{N + 3 \cdot f_a}{N + f_a} \quad (1)$$

Where $N$ represents the number of users in each beam, and for the sake of simplicity, it is assumed that the number of users in each beam is the same, and $f_a$ represents the number of extra frequencies reserved in each beam. When $N = 10$ and $f_a = 2$, $FR_{sys} = 1.33$, slightly greater than 1, can achieve quasi single frequency reuse effect.

3. Resource Scheduling Scheme Based on Inter-group Swap

3.1 Interference Pre-cancellation with THP

THP is a kind of precoding technique which is used when the condition of channel state information (CSI) is known at transmitter. The signal is pre-processed by pre-estimation of the channel before the signal is transmitted, so pre-equalization can be achieved to eliminate interference between users, the processing block diagram shown in Figure 2.
At receive side, receive signal $y$ is represented as

$$ y = H F B^{-1} v + n $$

(2)

signal processing matrix is $G$, output is $y'$, i.e.

$$ y' = G y = G H F B^{-1} + G n $$

(3)

To obey zero-forcing rule, need force

$$ G H F B^{-1} = I $$

(4)

Define

$$ H F = S $$

(5)

$F, S$ can be calculated by performing QR factorization on $H^H$ i.e.

$$ H^H = Q R $$

(6)

$$ F = Q $$

(7)

$$ S = R^H $$

(8)

$F$ is a unitary matrix, $S$ is a lower triangular matrix, define

$$ G = \text{diag} \{ s_{11}^{-1}, s_{22}^{-1}, \ldots, s_{KK}^{-1} \} $$

(9)

$$ B = G S $$

(10)

Then $B$ is a unit lower triangular matrix and is normalized matrix of $S$.

On the other hand, QR factorization can be accomplished by using Schmidt orthogonalization process. Let $a$ represent column vectors of $H^T$, i.e.

$$ a_i = [g_{i1}, g_{i2}, \ldots, g_{iN}]^T $$

(11)

if $a_i$ is linear independence, after Schmidt orthogonalization:

$$ b_j = \begin{cases} a_i, & i = 1 \\ a_i - \sum_{k=1}^{i-1} \frac{\langle a_j, b_k \rangle}{\|b_k\|}, & i \in [2, N_T] \end{cases} $$

(12)

$$ s_{i} = \|b_i\|, i \in [1, N_T] $$

(13)

$$ \hat{a}_i = a_i + 1/\|b_i\| \cdot n_i, i \in [1, N_T] $$

(14)

Therefore, the performance of interference pre-cancellation is determined by the value of $1/\|b_i\| (i=1,N_T)$, only when $1/\|b_i\|$ is comparatively small ($\|b_i\|$ comparatively large), THP can be used for interference pre-cancellation in satellite communication.

Considering the distance between the users, the position of the user in the beam and the coding order of the users, these factors affect the performance of the system through affecting the noise amplification factor $1/\|b_i\|$. Users’ noise amplification factor has a direct impact on the performance of THP.
Considering all the users' pre-coding output power is the same, when a user's $1/||\mathbf{\beta}_i||$ is larger, the channel noise will be amplified at the receiving end, resulting in a lower SINR. If there are a lot of users with low signal to noise ratio in the system, the degradation of the communication quality will cause the loss of the capacity and performance of the whole system. On the other hand, when the multi-beam satellite communication system serves a small number of users, it should also avoid the existence of individual users have a very low received signal to interference and noise ratio. From the point of view of practical operation, this paper adopts the principle of minimizing the maximum noise amplification factor of the same frequency users to make user scheduling, so as to determine the more effective THP user grouping method.

### 3.2 Resource Scheduling Scheme

It is assumed that there are K beams and N users in each beam and N sub-channels are used for the system downlink. Resource scheduling is to be completed from the frequency distribution and power distribution. Select a user from each beam of the K beams, a total of K users in the same group, and for this group of users assign the same sub-channel downlink transmission, the total need to repeat N times, the i-th ($i=[1,N]$) sub-channel is assigned to the i-th merged users. Number the beams. The beam at the center is defined as beam 1 and the other beams are numbered from the inner ring to the outer ring in a counter-clockwise spiral order outwardly from the center beam. Let $U_k = \{u_k^1, u_k^2, ..., u_k^P\}$ represent users in k-th beam not allocated before finding users in i-th group ($k=[1,K], P= N-i+1$).

1) Step a: pre-grouping

Firstly, the idea of pre-grouping all users is to find groups of users in each beam which have the same relative coordinates as their beam centers are defined as (0,0)

2) Step b: inter-group swap

For each group of users using the same frequency point, find all users whose $\text{SINR}<\text{SINR}_{\text{th}}$ ($\text{SINR}_{\text{Threshold, set as 5dB}}$), swap their group number with those users closest to the center.

3) Step c: Resource allocation

According to the result of grouping, for the users who stay in the same channel sequence, use the "Best-first" algorithm to sort and allocate the same frequency point for THP interference pre-cancellation.

#### Table 1 Inter-Group Swap Algorithm

| Step | Description |
|------|-------------|
| 1.   | Set number of iterations times swap; |
| 2.   | For all users in k-th beam, $U_k = \{u_k^1, u_k^2, ..., u_k^P\}$ |
| 1)   | forming a queue in which the distance between the user and its beam center is small to large, $D_k = \{u_k^{a_k}, u_k^{b_k}, ..., u_k^{x_k}\}$ |
| 2)   | forming a queue in which the SINR is small to large $S_k = \{u_k^{a_k}, u_k^{b_k}, ..., u_k^{x_k}\}$ |
| 3)   | find t users whose $\text{SINR}<\text{SINR}_{\text{th}}$ $S_{(k,t)} = \{u_k^{a_k}, u_k^{b_k}, ..., u_k^{x_k}\}$ |
| 4)   | swap the group number of $S_{(k,t)}$ with the first t users in $D_k$, er grouping after swapping become: |
| 3.   | repeat 2 for times swap times. |

### 4. Simulation Results

#### 4.1 Ratio of Low SINR Users

After swapping, change of ratio of low SINR users in system is shown in figure 3.
As shown in figure, after swapping, ratio of low SINR users decrease harply. When precoding output power to channel noise is 12dB, ratio of low SINR users decrease from 4.44% to 2.67% nearly 40% of origin ratio, the larger precoding output power to channel noise increase, the faster the ratio achieves zero.

4.2 Minimum User SINR
In addition to focusing on the ratio of the number of low signal to noise ratio users, in order to ensure the performance of user with poor signal transmission quality, for user with the lowest signal to noise
ratio, whether the performance improves, simulation results as shown above:

The minimum SINR in the system is improved after swapping. When the ratio of precoding output power to channel noise is 13dB, the minimum SINR in the system increases from -3.5dB to -2.3dB. And when the ratio of the pre-coding output power to the channel noise is increased, the promotion ratio tends to increase.

5. Summary
In this paper, the adaptability of THP in multi-beam downlink is treated as the main research object. Based on the influence factors of user location and coding sequence, the user packet scheduling model based on inter-group swap is designed. The performance of the proposed method is compared with that without the proposed method, which proves the rationality of the proposed algorithm. Among them, the inter-group swapping scheme significantly improves the fairness of the system without significantly reducing the average signal to interference and noise ratio and the average beam spectrum efficiency of the users in the whole system.

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