A Non-adjacent Feed Selection Method for Beamforming Performance Enhancement for Multi-beam Satellite Antenna

Yongjie Pu, Bing Wang, Yong Luo, Yuxin Cheng and Jianjun Wu

Institute of Advanced Communications, EECS, Peking University, Beijing, P. R. China
Email: a puyongjie@pku.edu.cn, b just@pku.edu.cn

Abstract. In recent years, user-centered beamforming systems have attracted increasing interest in the study of multi-beam satellite communication systems. In order to ensure service quality, the beam directivity of targets should have enough flexibility to bear the randomness of user locations. In this paper, a non-adjacent feed selection method is proposed to minimize the mean square error of beamforming and provide enough flexibility of the beam directivity at the same time.

1. Introduction
In recent years, satellite mobile communication has been widely applied in many areas due to its large coverage, long communication distance and flexible communication modes. Owing to the large territory of China, the terrestrial wireless communication system alone cannot guarantee effective Internet access or even telephone communication. In comparison, satellite mobile communication is not restricted by geographical constraints and thus provides good services for remote areas. Meanwhile, satellite mobile communication has played an irreplaceable role in many important fields such as earthquake relief and military defense [1]. Therefore, the development of satellite mobile communication has attracted increasing attention from the government.

The multi-beam satellite communication system was proposed in 1970s to enhance the signal quality in satellite mobile communication [2]. After years of rapid development, this technology is still facing a great challenge.

As beamforming is formed by the weighted superposition of single feed beams, it is inevitable that the Co-channel Interference (CI) exists. The seriousness of the CI increases with smaller central beam intervals, resulting in the decrease of channel quality. Therefore, the performance of beamforming, especially the main lobe bandwidth and the side lobe suppression, should be taken into consideration [3]. In addition, as the demand of users gets stricter, the single total-coverage beam cannot meet the requirements, leading to an increasing beam numbers. The increase of beam numbers results in additional beamforming network complexity, higher hardware resource consumption and more network cost. Meanwhile, more requirements on the performance of the beamforming algorithm are raised [4].

In order to improve the service quality of cell edge users, the concept of single beam for single user is proposed. The satellite communication not only aims to realize a complete coverage of the ground, but also provides higher service quality for the covered district. Researches focus on a user-centered service mechanism and analyze the adaptive phased array antenna technology. Former researchers have done comprehensive analyses on the concrete implementation of the beamforming network, using a most common feed selection method, the adjacent seven feeds [5]. However, the feed selection has not been well discussed, which also has obvious influence on the performance of beamforming. In this paper, a non-adjacent feed selection method is proposed and discussed [6].
The remainder of this paper is organized as follow. The system model is introduced in Section II. In Section III, the drawback of the traditional feed selection method is analyzed and a novel non-adjacent feed selection method is proposed. Simulation results of the performance of the proposed method are given in Section IV. Finally, Section V concludes the paper.

2. System Model
In the multi-beam satellite communication system, enhanced multi-beamforming technology is often used to improve the gain of the beam and effectively control the shape of the beam. In this technology, the target beam is the weighted sum of several feeds. In the case of the regular feed array, the most common method is the adjacent seven feeds, which is depicted in Figure 1. It can not only ensure the performance of beamforming within a certain range, but also decrease the complexity of feed selection.

![Figure 1](image1.png)

**Figure 1.** The method of adjacent seven feed sources

However, in the case of user-centered beamforming systems, the beam directivity of targets should have enough flexibility to bear the randomness of user locations. Due to the symmetry of feeds, the levels of the main lobe and side lobes are sometimes hard to control when the traditional adjacent feed selection is applied, leading to serious interface between beams and poor performance of the system.

Consider a case as follow. The pattern of the feed array is given in Figure 2, the same as the single feed direction pattern on the ground. The user starts at the origin point of the coordinates and moves in a direction of 150 degrees along the X-axis. Take a reference point at every 0.1 degree, as the center of the composite beam. Due to the symmetry of the feed array, only the case that the user moves from the origin point to the overlapped marginal location of beam 1, 2 and 3 should be considered. In this paper, four equal spacing points A, B, C and D are picked as the central location of the target beam.

![Figure 2](image2.png)

**Figure 2.** The pattern of the movement of the target beam

3. The Feed Selection Method

3.1 The Traditional Adjacent Feed Selection Method
In this method, when the center of the beam locates between A and D, the No.1 feed source is the nearest one to the center of the beam according to the basic geometrical relationship, so it is reasonable to choose the No.1 feed source (as the center) and six feed sources (from No.2 to No.7) around it as a combination.

The performance of beamforming in different locations is depicted in Figure 3. Take D as an example. Feed source No.1, No.4, No.5, No.6 and No.7 have greater effect on the right side of the beam, while No.2 and No.3 on the left side. More feed sources mean better performance of beamforming. Thus the right side of the beam at D have lower side lobes while the left side higher. This kind of asymmetry can cause obvious interface between beams.
3.2 Novel Non-adjacent Feed Selection Method
Take D as an example again. Assume the set including selected feed sources as ϕ, and then:

- Find the three nearest feed sources from the target beam, usually adjacent feed sources. For D, the No.1, No.2 and No.3 feed sources are selected. Include them into ϕ. They have the biggest effect on beamforming.
- There are nine adjacent feed sources around the three chosen feed sources. Their effect on beamforming is second to the latter. Choose N (0<N<9) feed sources from these nine adjacent feed sources and include them into ϕ as well to complete the feed selection.
- Two requirements on the chosen feed source set ϕ are shown as follow. First, the performance of beamforming should meet the requirements, including steering accuracy, -3dB bandwidth of the main lobe and the suppression of side lobe levels. Second, to decrease the complexity of beamforming network and keep amplifiers from nonlinear area, the number of feed sources should be as small as possible.

Therefore, the procedure of feed selection is shown as follow. First, set N=1 before the beamforming algorithm iterates through all possible feed source combinations and calculates the weight. Second, find the combination which minimizes the sum of mean square error. After that, judge whether the performance of beamforming meets the requirements. If so, the expected feed selection is found; otherwise, set N=N+1 and repeat the procedure above until the performance meets the requirements.

4. Simulation Results
Take D as an example. According to the simulation results, the level of side lobes cannot meet the requirements in any feed selection when the number of feed sources is less than seven. So consider the case where seven feed sources are chosen and simulate the performance of the proposed non-adjacent feed selection method.

After the iteration of all those combinations, the best combination is found, that is, No.1, No.2, No.3, No.4, No.6, No.9 and No.19, which is depicted in Figure 4 (a).
The pattern of beamforming in this case is depicted in Figure 4 (b). As in the graph, by applying the proposed method, the performance gets better on the suppression of side lobe levels, which is lower than -20dB. Consequently, the interface between beams can be decreased effectively. Meanwhile, the width of the main lobe is 0.6° which meets the requirements.

The reason for better performance is the symmetry of the combination of feed sources (including No.1, No.2, No.3, No.4, No.6, No.9 and No.19). In this case, the left and right side lobes suffer almost equal influence from these feed sources. Besides No.1, No.2 and No.3 feed sources, No.9 and No.19 have a greater effect on the left side of the beam, which solved the problem in the traditional method, namely the poor suppression of left side lobes.

Then, take C as another example and repeat the procedure. The simulation results are depicted in Figure 5 (a) and Figure 5 (b). As can be seen in Figure 5 (b), compared with the traditional method, the non-adjacent feed selection method can suppress the left side lobes more effectively, leading to a better waveform symmetry. Besides, the requirements of the system are all met, which shows the effectiveness of the new method.

As for the number of feed sources, the seven feeds selection already meets the requirements. Although extra feed sources can further improve the accuracy of beamforming, the change is less meaningful, and it will not be discussed in the paper.
5. Conclusion
In this paper, a novel non-adjacent feed selection method is proposed to improve the performance based on traditional adjacent feed selection method. The proposed method decreases the level of side lobes and relieves the interface between beams, resulting in more coverage and beam directivity flexibility while retaining the quality of the beamforming. Results show that the performance of the proposed method meets the requirements of user-centered beamforming systems.

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7. References
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