Beam- edge Performance Improvement for Multi-beam Satellite Communication via Joint Downlink Transmission

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***Abstract*—In multi-beam satellite communication systems, all information is to the gateway stations that makes it easy to process joint transmission. This paper discusses two conditions that all receivers are in beam edge area or not. Full joint transmission is used when receivers are all in beam edge area and partly joint transmission is used when one of receivers are out of beam edge area. Then the simulation result shows that joint transmission improves the system performance, and when edge area radius is 0.3 times beam radius, the system performance is optimal.**

***Keywords*—Joint Transmission, Mobile Satellite Communication, Multi-beam**

I. Introduction

Nowadays, satellite communication becomes one of the most important communication modes. And along with the development of antenna technologies, multi-beam satellite communication is more and more widely used in modern satellite communication systems. Multi-beam satellite communication systems have advantages of larger coverage area and flexible frequency reuse. It also means that coverage area of multi-beam satellite is combined by many beams. To ensure complete coverage, the beams should be overlapping. So the problem that one beam may have influence on other means should be taking into account.

In terrestrial cellular communication systems, the interference from other cell also affects the system performance. Many methods are presented to reduce the interference from other cell. One of the methods is joint transmission. Joint transmission is a method to make all the base station transmit together. Then the interference from other cell will be useful. It effectively improves the system performance. However, when processing joint transmission, all the base stations must share their information. With the number of base stations increases, the cost of sharing information will increase rapidly. As for multi-beam satellite communication systems, such problem is settled in the course of nature. Because there're only several gateway stations in satellite communication systems, and it is easy for gateway stations to share every information. As a result, joint transmission is more suitable for multi-beam satellite communications.

This paper firstly introduces a k-beams satellite communication system model. Then the satellite channel is discussed. As the satellite channel is generally LOS channel, feasibility of joint transmission is also discussed here. For two conditions that all receivers are in beam edge area or not, two joint transmission methods are presented. Then a simulation of these two methods is executed. At last the simulation result shows that how the optimized radius of edge area should be.

The rest of the paper is organized as follows. In Section II, a K-beams satellite communication system model is presented, and the satellite channel is discussed. Then two joint transmission methods are employed in Section III, and their applicative conditions are also discussed. Then in Section IV, a simulation is executed. From the simulation result, an optimized edge area radius is given. And in Section V, the concluding remarks are presented.

II. SYSTEM MODEL

A K-beams satellite communication system model is presented here. As mentioned in Section I, these K beams use the same frequency for downlink transmission, which means this system is a single frequency network. Simply, there's only one gateway station in this network, and all the signals are from this gateway station. Hence all the signals can be processed simultaneously. For systems that have several gateway stations, a terrestrial wired network is needed to connect all the gateway stations. Because there's not a lot of station, this terrestrial wired network is not complex and low-cost.

Figure 1 shows the system model. Gateway station plays the transmitter. It transmits signals for each beam to satellite in space, and then the satellite retransmits each signal to target beam. Receivers in each beam receive the signals and demodulate its own signal. The satellite here only amplifies the signal power. So without regard to nonlinearity of amplifier, the LOS single path channel can be given by

$$h_{k,i} = AG_{Tx}G_{Rxi}G_k(\theta_i)\alpha e^{-j2\pi f_c\tau_i} \tag{1}$$

where A is retransmit gain, G_{Tx} and G_{Rxi} are the antenna gain of transmitter and receiver, $G_k(\cdot)$ is radiation pattern of beams, θ_i is position angle of receivers, α is path loss, f_c is carrier frequency and τ is transmission delay.

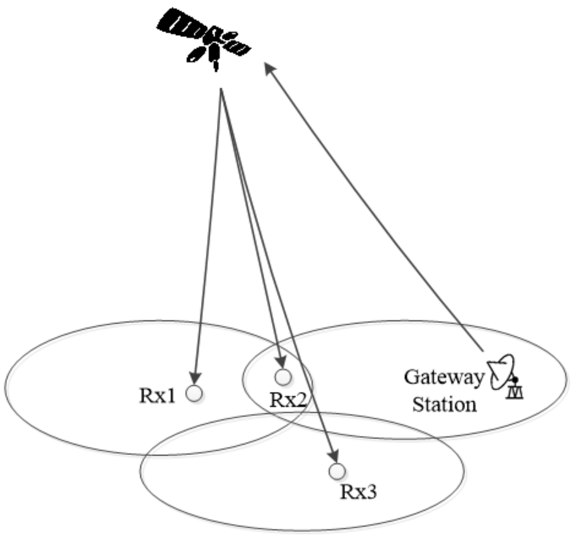

Figure 1. model of k-beams satellite system

Supposing antenna gain of every receiver is identical, (1) can be written as

$$h_{k,i} = \alpha_i G_k(\theta_i)e^{-j2\pi f_c\tau_i} \tag{2}$$

In multi-beam satellite communication systems, each beam has one receiver which uses the same frequency. For example, in an OFDM based system, receivers in different beams can use the same sub-carrier. Assuming the signals sent to the *i*th receiver is $\boldsymbol{x}_i$, then the received signal in is

$$\boldsymbol{y}_i = \boldsymbol{H}_{i,i}\boldsymbol{x}_i + \sum_{k\neq i}\boldsymbol{H}_{k,i}\boldsymbol{x}_k + \boldsymbol{n}_i \tag{3}$$

where $\boldsymbol{H}_{k,i} \in C^{n\times n}$ is channel matrix for signals of k*th* beam received by receiver in i*th* beam and $\boldsymbol{n}_i \in C^n$ is Gaussian noise. Here $\boldsymbol{H}_{k,i}$ is different according to subscript k, because all the beams are generated by different feeds. These feeds may be form different feeds array or even different satellite, and the channel matrix can be orthogonal [1]. In (3), the second part is treated as interference. When receiver locates in beam edge, the interference may seriously increases, leading to low SINR that reduces system performance. In order to improve system capacity in beam edge, a joint transmission method should be used to eliminate the interference of other beams.

III.JOINT TRANSMISSION

A. *Three-beams Joint Transmission*

To employ joint transmission, signals of every beam should be pre-coded before transmission. Let $\boldsymbol{x}=[\boldsymbol{x}_1,\boldsymbol{x}_2,...,\boldsymbol{x}_N]$, and $\boldsymbol{H}_\text{i}=[\boldsymbol{H}_{1,i},\boldsymbol{H}_{2,i},...,\boldsymbol{H}_{N,i}]$. Then the received signal in i*th* receiver can be given by

$$\boldsymbol{y}_i = \boldsymbol{H}_i\boldsymbol{W}\boldsymbol{x} + \boldsymbol{n}_i \tag{4}$$

where $\boldsymbol{W}=[\boldsymbol{W}_1,\boldsymbol{W}_i,...,\boldsymbol{W}_N]$ and $\boldsymbol{W}_\text{i}$ is the pre-code matrix of i*th* beam.

In multi-beam satellite communication systems, all the information can be shared among gateway stations. So the transmitter can pre-code all signals together. In consideration of power limit of satellite, the power constraints is

$$E[\sum \text{tr}(\boldsymbol{x}_\text{i}\boldsymbol{x}_\text{i}^H)]=\text{tr}[\sum \boldsymbol{W}_\text{i}\boldsymbol{W}_\text{i}^\text{H}] \le P_\text{total} \tag{5}$$

[2] gives

$$\boldsymbol{W}=\boldsymbol{H}_\text{T}^H(\boldsymbol{H}_T\boldsymbol{H}_\text{T}^H)^{-1} \tag{6}$$

where $\boldsymbol{H}_\text{T}=[\boldsymbol{H}_{1,i}^T,\boldsymbol{H}_{2,i}^T,...,\boldsymbol{H}_{N,i}^T]^T$.

Joint transmission using above method makes all transmitters send signal to every receiver. As for multi-beam satellite communication systems, signal power has 3dB attenuation in beam edge. So when receiver is in beam edge, signal powers of the three adjacent beams are the same. In this condition, the signals of three adjacent beams can use joint transmission. That means receivers in edge area of three beams can use the same subcarrier frequency, and these three beams can use joint transmission to improve system performance in such edge area.

B. *Partly Joint Transmission*

When receivers are not in beam edge, signal power of other beams may have more than 20dB attenuation. In this condition, it is difficult for receivers to detect signals from other beams. So using a full joint transmission may lead to performance reduction. Then a partly joint transmission should be employed to solve this problem.

Partly join transmission uses pre-code matrix to eliminate interference from other beams. Transmitter of each beam just send signal to receivers in its own coverage area. So the received signal in i*th* receiver can be given by

$$\boldsymbol{y}_i = \boldsymbol{H}_{i,i}\boldsymbol{W}_i\boldsymbol{x}_i + \sum_{k\neq i}\boldsymbol{H}_{k,i}\boldsymbol{W}_k\boldsymbol{x}_k + \boldsymbol{n}_i \tag{7}$$

Here the power constraint is the same as that in full joint transmission, which is given by (5). In this condition, transmitter of every beam only needs to pre-code its own signal which is send to receivers in its own coverage area.

(7) shows that the interference is

$$\mathrm{I}_i = \sum_{k \neq i} \boldsymbol{H}_{k,i} \boldsymbol{W}_k \boldsymbol{x}_k \tag{8}$$

And [3] gives a method to eliminate the interference of other beams in LOS satellite channel. The pre-code matrix can be generated as

$$\boldsymbol{W}_k^{\,m} = (\boldsymbol{H}_k^{\,m})^{-1} \boldsymbol{W}_r \tag{9}$$

where the channel matrix is decompose as $\boldsymbol{H}_k = \boldsymbol{H}_k^{\,m} \otimes \boldsymbol{H}_k^{\,m-1} \otimes ... \boldsymbol{H}_k^{\,1}$, and interference is decompose as $\sum_{k \neq i} (\boldsymbol{H}_{k,i}^{\,\mathrm{m}} \boldsymbol{W}_k^{\,m} \otimes \boldsymbol{H}_{k,i}^{\,\mathrm{m-1}} \boldsymbol{W}_k^{\,m-1} \otimes ... \boldsymbol{H}_{k,i}^{\,1} \boldsymbol{W}_k^{\,1}) \boldsymbol{x}_k$.

IV. SIMULATION RESULT

In the simulation, a three beams model is employed. Every beam has one receiver using the same subcarrier. Carrier frequency is 2GHz, and system bandwidth is 20MHz. Satellite channel is LOS, without shadow fading.

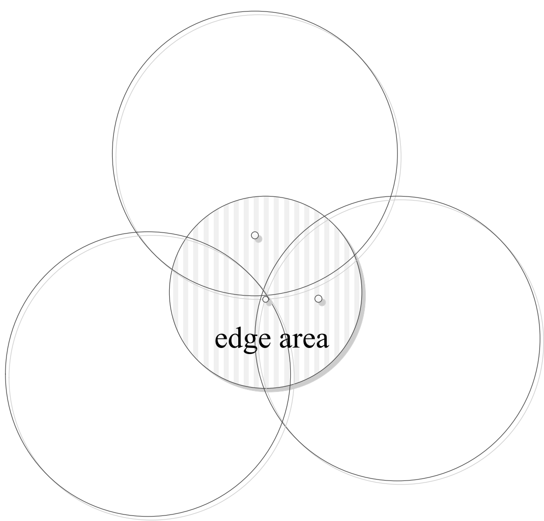

Figure 2. 3-beams model with edge area

Two conditions are considered in the simulation. In first condition, three receivers are all in the edge area which is marked in Figure 2. These three receivers use full joint transmission to improve the system performance. In second condition three receivers are not all in the edge area. Partly joint transmission will be used in such condition. The simulation changes the radius of the edge area, and the system performance of two conditions is as Figure 3

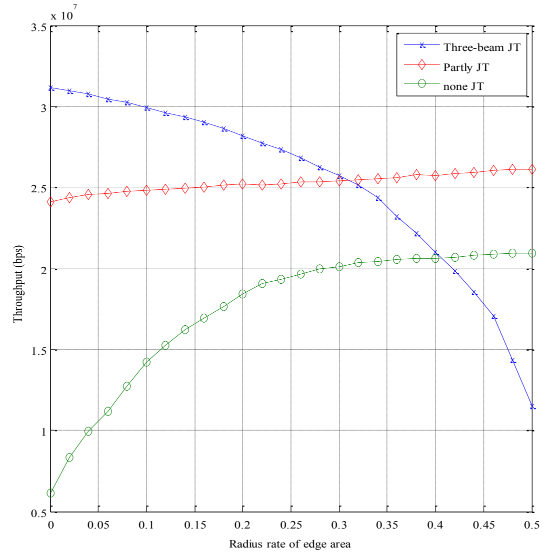

Figure 3. Simulation result

In Figure 3, when the edge area is small, interference power is the same level as signal power. When using three-beams joint transmission, the interference signals become useful signals. So the performance is the best. Meanwhile, in this condition, interference is huge so that system performance is serious decrease without joint transmission. As radius of edge area increases, interference power gradually reduces. Because three-beams joint transmission uses signals of other beams. When the signal power of other beams reduces, the system performance will drop together.

From the simulation result, when radius rate is above 0.3, system performance is better with partly joint transmission. So an optimized strategy is to differentiate two conditions with radius rate 0.3. In other words, when receivers are all in edge area, full joint transmission is used to improve system performance. And when one of the receivers is out of edge area, partly joint transmission should be used. Moreover, with GPS function, locations of every receiver are knowable. The problem to be further discussed is how to manager resource in frequency domain and time domain with such optimized strategy.

V. CONCLUSION

In this paper, interference in beam edge of multi-beam satellite communication system is discussed. Then joint transmission methods are employed to eliminate interference in beam edge. Two conditions are considered in this paper. One is condition that all receivers are in beam edge, and another condition is that not all receivers are in beam edge. These two conditions need different joint transmission method. Then a simulation is executed. And the result shows that the optimized radius of edge area is 0.3 times beam radius.

ACKNOWLEDGMENTS

This work is supported by the National Science Foundation of China (Grant No. NFSC #61071083) and the National High-Tech Research and Development Program of China (863 Program), No. 2012AA01A506. Corresponding author: Jianjun Wu; Phone: +86-10-62752848; E-mail: just@pku.edu.cn.

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