The performance of the multi-beam satellite systems with a new bandwidth sharing algorithm

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Abstract :

An efficient resource allocation is important to guarantee the best performance with a fair distribution of multi-beam satellite capacity to provide satellite multimedia and broadcasting services. In this way, available bandwidth and capacity problems in new satellite system likes Multi-Input-Multi-Output (MIMO), exploring new techniques for enhancing spectral efficiency in satellite communication has become an important research challenge. In this aspect, multi-beam or frequency reuse can be considered as a promising solution to solve spectrum scarcity problem. In this paper, a new bandwidth sharing algorithm for satellite systems under multi-beam technique is proposed. Furthermore, by using the above framework, capacity of multi-beam satellite system based the number of antenna was simulated and compared them to obtain a solution for designing the next generation satellite systems. Therefore, by using the multi-beam and multi antennas satellite parameters considered in the first step, the bit error rate was achieved by 4-QAM and 4-PSK modulations based on the number of antennas.

Keywords: Satellite, Multi-beam, Frequency reuse, Fifth generation, Bandwidth sharing, Digital modulation, Capacity, Path loss, Rain attenuation, Bit error rate.

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1. Introduction

Satellite systems, which have numerous beams for receiving and transmitting communication data are very imperative in the development of space communication without any error. Therefore, frequency reuse factor and more antennas are two factors to design next generation satellite networks. When a satellite system has huge numerous antennas, satellite capacity enhanced with them. Satellite systems with different antennas in uplink and down link, all of the receivers were divided in the ground side in small cells for providing satellite services. In this scenario, each antenna from satellite can provide a suitable traffic for cells. In up and down space link between small cells and satellite need different power and bandwidth. To address this challenge, several scenarios have been proposed based only prefect channel which all of information space channel is known [1,2,3].In future satellite system, there is resource scarcity for users with small cell. Therefore, a resource management method is very important. In previous satellite systems, there is a unique resource allocation for each small cell. This is an unsuitable solution for managing resource in satellite systems. Because there are many other cells at one time or different times which need different resources such as bandwidth. Therefore, space industry needs a suitable solution for dividing resource between cells [4]. In next generation satellite networks (5G-satellite networks) with a long life in space, it is very important to update all of provision sources between satellite and small cells. So, a new resource management is provided in [5], some new algorithm such as power consumption to space link is provided in [6]. A new algorithm based on max/min signal to noise interference and optimized data allocation is proposed in [7], the typical bandwidth sharing algorithm mention based on service demand between cells for recent years. This algorithm can decrease a bit error rate of satellite systems when the number of transmitter or receiver antennas enhance in satellite side or cells side. Consequently, this is a very important result as the signal to noise ratio distribution based on the number of antennas, such as the outage communication exchange probability. For each new satellite network will be predicted, there are many transmitter and receiver antennas for each small cell to provide many new space services such as mobile satellite phone [8,9,10]. In [11], a power allocation method is provided to satellite system based on the uncompleted action in the channel state information (CSI), and a new routing way provides achievable total throughput in satellite system. In [12], a solution for resource management based on traffic between satellite system and small cell was proposed. In [13,14], a new solution for satellite system provided based on traffic demand. A new technique based on frequency reuse for achieving high data rates in the satellite is provided in [15].

For a new satellite system with many beams, a suitable resource management is very important for having a high spectral efficiency. In [16], two algorithms based on provision power and bandwidth of many beams was surveyed. In [17], the authors surveyed the resource solution in satellite system with many antennas for having best space traffic was proposed.

One mathematical algorithm to achieve the capacity of the satellite systems with many antennas is to use multi beams for a satellite system based on different space traffics. These traffics are in depended at the ground station side by signal processing solutions [18]. In [19], an optimization resource management based on the space traffic rate and free space conditions such as rain attenuation is simulated.

A new resource allocation method based on the feedback communication exchange for satellite with many antennas has been surveyed [20]. In [21], a resource management based on space multimedia traffic for satellite system has been proposed. In [22,23], a resource allocation satellite system with, many antennas has been proposed which provide only resources for the active user in cells.

In [24], the authors provide a satellite network with different antennas analyze the maximum capacity in downlink for two cases:

- Dedicated resource allocation algorithm
- Sharing resource allocation algorithm

The satellite systems with many transmitter and receiver antennas have the main role in future space wireless communication, which prevents interference between different cells.

In new satellite communication systems, fixed services use C and K bandwidth frequencies. However, in recent years, traffic demand for broadband satellite services has surpassed that of previous decades; therefore, K_u and K_a bandwidth frequencies have given more attention to mobility services [25]. One algorithm that makes it possible to achieve the power of the satellite systems with numerous antennas upholds the use of numerous beams between the satellite systems and the side of the ground station for different space traffics. These space traffics are hinged on the side of the ground station through signal processing solutions. Thus, the frequency of reuse and the provision of more antennas are two important factors in the development of next generation satellite systems [26]. In previous satellite systems, there was a peculiar resource allocation for each ground cell. This is an unsuitable solution for the management of resources in satellite systems. This is due to the fact that there are many other ground cells with a different time duration which need different resources such as bandwidth or power [27,28]. Finally, the bandwidth sharing management problem is a very important factor for designing a satellite network system to enhance capacity allocation. Therefore, in this paper, an algorithm is provided for this reason. The rest of this paper is composed as follows. In Section 2, the system model and the main formulations are proposed. In Section 3, the new bandwidth sharing algorithm is provided. In Section 4. Simulation results based on the satellite system architecture are provided .Finally, section 5 concludes the paper.

2. Satellite system with different antennas model

In this paper, we focus on the effect of enhancing the number of beams which M is transmitter antennas in satellite side and N is receiver antennas in cell (ground station) side. We formulate bit error rate for two digital modulations include 4-QAM and 4-PSK with respect of the estimation error as independent complex Gaussian noise. As seen in Fig.1, a satellite system, which has one antenna on the side of the satellite, is used to cover different or common ground cells. In this scenario, each beam should have a minimum bandwidth for the provision of space services or traffics. In the scenario investigated by the authors, a large number of beams can be used to cover the same area at the side of the ground cell. [27,28]. As we have seen in Fig.1, There is a satellite system which has many antennas cover different or common cells. In this scenario, each beam should have a minimum bandwidth for provision space services or traffics.

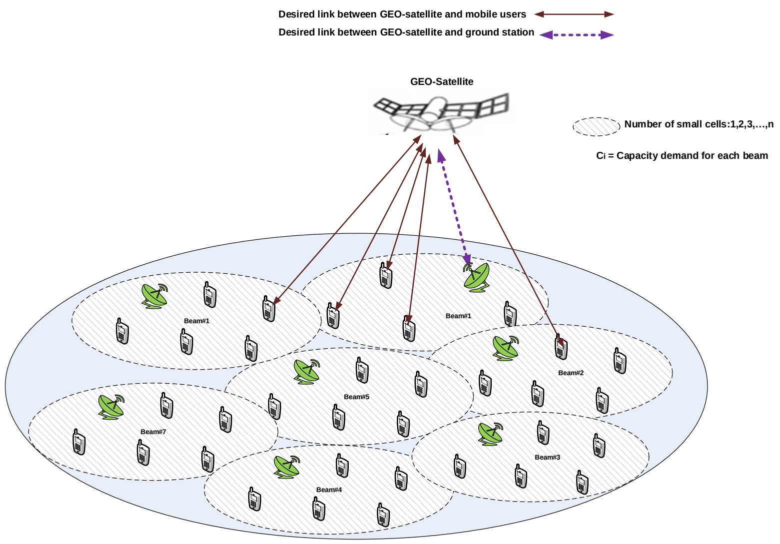

Fig.1.Multi-beam satellite communication system.

Also, a large number of beams can be used to cover the same area in ground side. In this context, some efficient bandwidth sharing techniques enhance achievable capacity with good quality of service.

In this paper, a satellite system with different antennas has the following advantages:

1. Down link power and up link power from satellite is divided among beams, and the bandwidth remains constant for each beam. Ultimately, the total bandwidth increases by the number of beams.
2. Space link performance improved as the number of beams increases.
3. There is broaden coverage of satellite system from the replacement of several beams.

3. The bandwidth sharing between for each satellite beam

In this paper, we assumed that the minimum and initial bandwidth of the i^{th} beam for satellite system is B_{min} and B_{init} based on space service level agreements (SSLAs). In addition, the total bandwidth for satellite was B_{total} and K was the number of beams in the investigated scenario. Table (1) shows a new bandwidth sharing formulation in the satellite system based on priority beams which was specified in SSLAs. We suppose that the allocated capacity C_{bi} of the i^{th} beam is calculated according to the following equation (1)[21]:

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$$C_{bi} = \frac{\eta \times B_{total}}{k} \qquad (1)$$

Where η is the frequency efficiency according equation (2):

$$\eta = \frac{r \times \log_2(O)}{1 + \alpha + \frac{B_{init}}{B_{\min}}} \qquad (2)$$

Which r is the modulation rate in uplink/downlink, O is the order modulation, α is roll of factor off in pulse shaping and k which is a frequency reuse factor of the i[th] beam. In this part, beams are considered in a single cell. B_{min} is the minimum bandwidth for each beam of satellite systems. In table (1), shows a new bandwidth sharing formulation in satellite system. In addition, the coverage probability (CP) of the multi-beam satellite system was investigated and simulated as the probability of receiving the signal to noise ratio (SNR) by the user for each small cell, and was found to be larger than a specific threshold level T with respect to the path loss factor α [29]. Note that the coverage probability is independent of the number of antennas on the side of the satellite or cell. When the threshold T is greater than the first value, coverage probability in closed form can be computed (3):

$$cp = \frac{a \times \sin(\pi / a)}{\pi \times T^{1/a}} \qquad (3)$$

The coverage probability for each cell in the satellite system structure is presented in Fig.2. In this figure, path loss factor must be greater than the second value because the coverage probability of the satellite system has a better performance than the fourth and sixth values in the coverage probability. This is due to the fact that noise and propagation delay have less effect in channels between the satellite and ground cells in the investigated scenario.

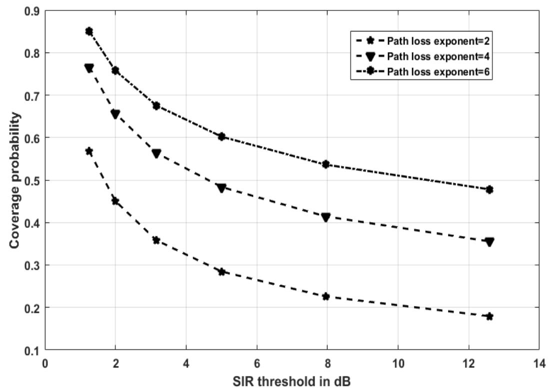

Fig.2.Comparison of coverage probability versus power constraint

Table.1.Add bandwidth sharing algorithm

Step 1.Set minimum need bandwidth for i[th] beam (B_{min})
Step 2.Set initial bandwidth for i[th] beam from satellite(B_{init})
Step 3. Compare between B_{min} and B_{init} for i[th] beam
If $B_{\min} \le B_{init}$,
• Add bandwidth for i[th] beam is: $B_{add} = B_{init} - B_{\min}$,
Step 4. For another beams ($j \neq i$)
If $B_{\min} \ge B_{init}$,
• Required bandwidth for j[th] beam is: $B_{\min} + (\beta \times B_{add})$,
Which β is some of region B_{add} based on space service level agreements (SSLAs).

In this paper, we supposed M-QAM and M-PSK has (M − N + 1) degrees of freedom, where the weight is a function of the number of transmit antennas M on satellite side and the number of receiver antennas N on cell side. The space channel between satellite and cell with different antennas is modeled as a Rayleigh flat fading channel and can be obtained by an M × N matrix **H** with zero mean and variance has unit value. Also, each entry of matrix **H** is shown in h_{mn}. h_{mn} represents the space channel gain between the m[th] receiver antenna in cell side and the nth transmitter antenna in satellite side. Received signal vector **R** can be provided as [21], where fc denotes the carrier frequency, C_0 is the speed of light and d is the distance between the transmitter antenna and receiver antenna. Moreover, the amount of rain attenuation showed by A Rain-attenuation. **S** is transmitter symbol from the side of the satellite and **I** is the unique matrix. Finally, a_{mn} denotes the space channel gain on the between the transmitter antenna and the receiver antenna which can be taken as follows (4):

$$\mathbf{R} = \mathbf{H}_{mn} \times \mathbf{S} + \mathbf{N},$$

$$\mathbf{H} = a_{mn} \times \exp\left(-j \times \frac{2 \times \pi \times f_c}{C_0} \times d\right) \times \exp\left(\frac{-A_{Rain-attenuation}}{10}\right), (4)$$

$$a_{mn} = \frac{C_0}{4 \times \pi \times f_c \times d},$$

$$\mathbf{N} = CN(0, \sigma^2 \times \mathbf{I}).$$

In this formulation, some beams had more bandwidth. Consequently, bandwidth management for capacity allocation is very important. Hence, it was discussed in the previous section. The proposed multi-beam satellite capacity was obtained as follows (5):

$$C_{multi-beam} = \min(M, N) \times \log_2(1 + SNR \times \mathbf{H} \times \mathbf{H}^* \times \max(M, N)) \qquad (5)$$

In [13], by recognizing the bit error probability, the authors obtain the BER expression for M-QAM and M-PSK in AWGN channel as (6-8):

$$BER_{M-QAM} = \frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left(\frac{1}{2}\times(1-\mu_0)\right)^{N-M+1}\times \quad (6)$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_0)\right]^{K} +$$
$$\frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left[\frac{1}{2}\times(1-\mu_1)\right]^{N-M+1}\times$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_1)\right]^{K}.$$

$$BER_{M-PSK} = \frac{2}{\max\times(\log_2 M, 2)}\times \quad (7)$$
$$\sum_{K=0}^{\min(2,|M/4)|}\left(\left[\frac{1}{2}\times(1-\mu_K)\right]^{N-M+1}\times \sum_{L=0}^{N-M}\binom{N-M+L}{L}\times\left[\frac{1}{2}\times(1+\mu_K)\right]^{L}\right).$$

Where (μ_i) is as follow:

$$\mu_i = \sqrt{\frac{\overline{\gamma_s}\times\sin^2((2\times i-1)\times\pi/M)}{1+\overline{\gamma_s}\times\sin^2((2\times i-1)\times\pi/M)}}. \quad (8)$$

4. Simulation results

In this section, a satellite system with M transmits antennas and *N* receives antennas was analyzed by using MATLAB software. For the simulation, a multi-beam satellite system model is set up. The parameters of the system are shown in Table.2. Finally, in Table.3, the allocated capacity C_{bi} of the i^{th} beam with/without bandwidth sharing algorithm have compared together. As it is shown in Fig.3 by increasing the receiver antennas, the capacity of the multi-beam satellite system and spectral-Efficiency, up 15 dB SNR is increased. As it is observed in Fig.4, the Spectral-Efficiency increases by the increment of the signal to noise ratio for the different numbers of the receiver antennas in base stations.

Table. 2. Parameters for a typical satellite system [30,31]

Definition Parameter	Value
Satellite frequency (f_c)	11-14 GHz
Distance satellite from earth (d)	≈ 36000 Km
Transmitter antenna (M)	1
Receiver antenna (N)	4,6,8 and 10
Total Bandwidth of each spot beam(B_{Total})	530 MHz
Minimum Bandwidth of each spot beam(B_{min})	36 MHz
Initial Bandwidth of ten spot beams(B_{initt})	[36,45,55,40,45,72,36,106,45,50] MHz
Signal to Noise Ratio	From 0 to 30 by 5 step size
Light speed (C_0)	3×10^8 m/s
Rain attenuation ($A_{Rain-Attenuation}$)	3 dB
Order digital modulation (O)	4 for PSK and QAM
Modulation rate (r)	2/3,5/6 and 9/10

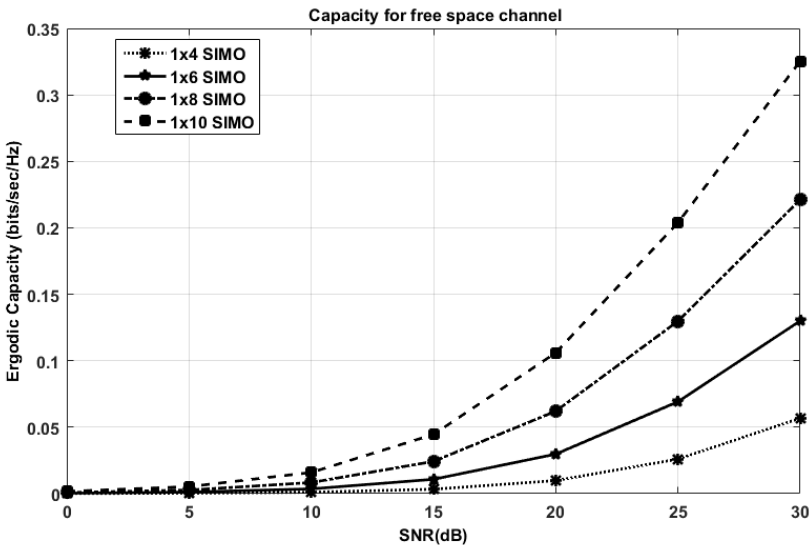

Fig. 3. Satellite system capacity with single antenna for satellite and multi-antenna for beams versus SNR

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Table. 3. Compare between with/without bandwidth sharing algorithms for the allocated capacity C_{bi} of the i^{th} beam

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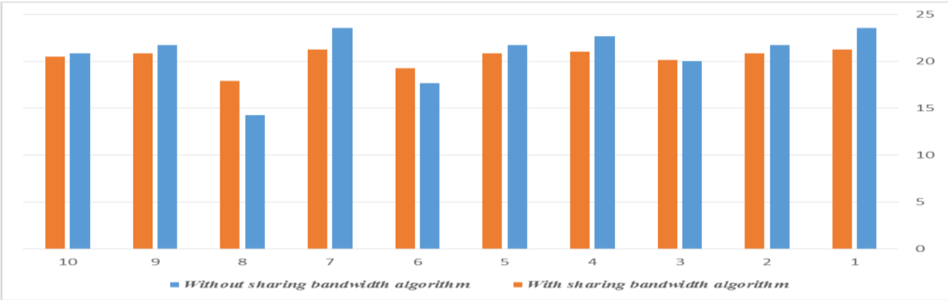

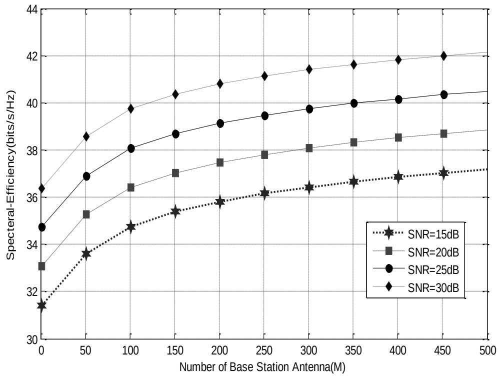

Fig. 4. Spectral-Efficiency for each beam versus number of antennas (Bit/Sec/Hz)

As it is observed in Fig.5, when there is BPSK modulation in satellite system with many beams, the BER of the satellite system decreases by the incremented of the signal to noise ratio. Also, with the same SNR, BER increases as N decreases. It can be observed when the SNR is almost from 5 to 7 dB for satellite system by using N=10, 8 and 6, there is almost 10^{-5} bit error in the receiver.

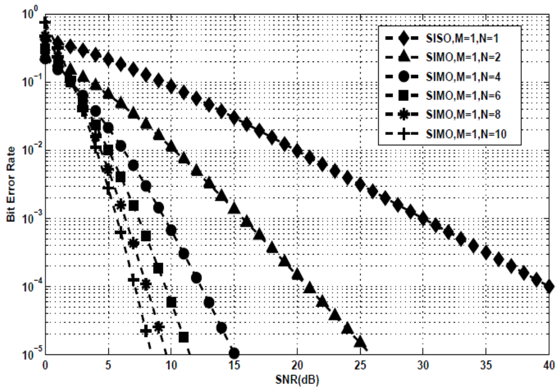

Fig. 5. BER performance of 4-PSK SIMO with M=1, N = 10,8,6,4 and 1.

Simultaneously, In Fig.6, when there is 4-QAM in multi-beam satellite system, there is the same result looks like BPSK modulation. It can be observed when the SNR are almost from 7 to 11 dB for satellite system by using N=10, 8 and 6, there is almost 10^{-5} bit error in the receiver. As seen in these figures, it can be concluded that bit error rate increases with an increase in error estimation factor and 4-QAM is better than 4-PSK based on the increase in the estimated error factor.

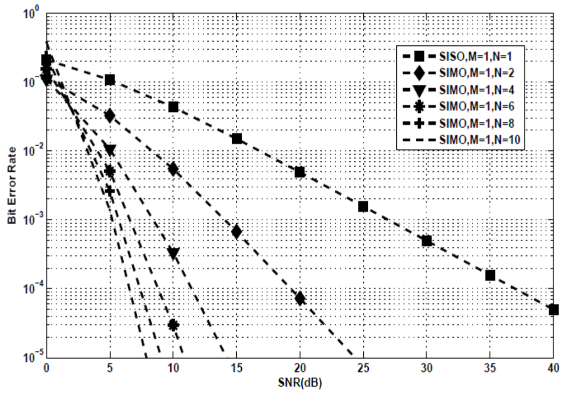

Fig. 6. BER performance of 4-QAM SIMO with M=1, N = 10,8,6,4,2 and 1.

5. Conclusion

In this paper, a new algorithm for multi-beam satellite system based on the bandwidth sharing was evaluated. Also, the performance of the satellite system with perfect space channels was compared based on the digital modulations such as 4-QAM and 4-PSK. As seen from the simulation results, an increase in the number of transmitter antennas in multi-beam satellite systems causes an enhancement in capacity. Furthermore, it should also be mentioned that the trade-off between the capacity and the error rate of satellite system based multi-beam satellite systems are important. As a result, it goes beyond the scope of this paper and it remains a next generation satellite system.

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