Jointly power and bandwidth allocation for a heterogeneous satellite network

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Abstract- **Due to lack of resources such as transmission power and bandwidth in satellite systems, resource allocation problem is a very important challenge. Nowadays, new heterogeneous network includes one or more satellites besides terrestrial infrastructure, so that it is considered that each satellite has multi-beam to increase capacity. This type of structure is suitable for a new generation of communications, which leads to a specific benefit of using the available resource in wireless communication systems. The multi-beam technology is one of the multiple access methods for new satellite systems that are similar to very high throughput satellites systems. Therefore, in this paper, our proposed algorithm is mainly the jointly power and bandwidth allocation of satellite systems to each beam and it is simulated considering the limitation of the total transmission power and bandwidth constraints for any beams. Furthermore, a bandwidth sharing algorithm is provided to dedicate extra bandwidth among beams. Finally, the total capacity of our proposed system model, which is heterogeneous network is obtained based on some parameters such as frequency reuse, modulation rate and total number of users for each beam. This comparison shows that the proposed algorithm allows maintaining the optimal capacity allocation to use a new satellite network.**

Index Terms- Hybrid integrated satellite-terrestrial network, Bandwidth sharing, Frequency reuse, Multi-beam.

I. INTRODUCTION

Recently, fifth generation (5G) technology is rapidly developing in wireless communication. This technology should provide many technical requirements such as more capacity, more security and less latency rather than previous generation technology,i.e. to the fourth generation (4G)[1, 2]. According to 5G-public-private-partnership (5G-PPP)

Manuscript received 18-June-2018 and revised 5-October-2018,
Accepted on 4- December-2018

P- ISSN: 2322-4088
E- ISSN: 2322-3936

recommendations, providing any services in every time and everywhere based on 5G propaganda are a big challenge to implement future wireless communication network [3].

In future wireless networks based on 5G technology, it is very important that each communication system causes little latency to communicate among mobile users in new heterogeneous satellite networks (HSN) which including one or more satellites in space constellations and infrastructure equipment. In this way, china has provided a national project which includes a space-terrestrial integrated network (STIN)[4, 5]. Based on northern satellite research (NSR) in 2015, each satellite system is exposed to many challenges in new generation communication. For example, the latency subject is one of them. This parameter from non-geostationary orbit (non-GEO) satellites to terrestrial equipment or mobile users is approximately from 20 (ms) to 50 (ms) which is longer than the considered latency for new generation communication networks. Nevertheless, non-GEO satellites are the best candidate in heterogeneous networks for remote areas where there is no terrestrial equipment. These kinds of satellites are located at low orbital heights. Hence, non-GEO satellite systems have low latency other than GEO satellite systems. To ensure more capacity in 5G wireless networks, satellite systems have important merit because they have large-scale coverage to provide a seamless connection between terrestrial systems. Due to the limitations of satellite systems to provide any kind of satellite services and lack of satellite resources, the efficient satellite resources management, e.g. power and bandwidth, are crucial for economic satellite systems. Hence, this kind of new heterogeneous network should be used on for non-delay sensitive service such as fax and data[3].

To provide more capacity, specific techniques in a satellite system will be required in heterogeneous satellite networks. New satellite systems, based on multi-beam, have been surviving in recent years. This type of communication system has capacity improvement compared to older satellite systems with no this kind of technology. In multi-beam satellite systems, the space antenna can provide a number of spot beams in a big territory. However, each beam will compete with other beams for scarce resources to achieve satisfactory communication[6]. This is due to the fact that the traffic demand is potentially highly asymmetrical among elements in satellite networks. Therefore, in order to achieve good matching between the offered and the requested scarcity, resource allocation, a satellite requires a certain degree of flexibility in allocating power and bandwidth resources[7]. Multi-beam satellite systems with regular frequency reuse and uniform power allocation cannot satisfy requirements such as capacity increment. Therefore, it is a motivation to investigate new transmission schemes in order to replace it with the current structures [8-10]. Most of satellite networks, based on statistic allocation scheme, are designed to allocate a fixed power for each beam. This type of resource allocation causes a waste of resource allocation when the traffic demand of the beams is high. Therefore, based on priority mobile users, type of space services and available sources, an efficient satellite resource allocation is very important[6].

Lei and Castro have designed a novel multi-beam satellite system based on jointly optimizing power and bandwidth allocation, in order to provide the best match of the asymmetric resource requests[11]. However, the proposed system model can allocate power and bandwidth appropriately. In[8], a multi-beam satellite system with a number of spot beams based on two types of characteristics was provided to obtain optimum capacity for each small beam.

In this system model, it is assumed that space channel has rician distribution and each beam has an elevation angle for a specific region. Also, one algorithm for obtaining propagation delay, to get average propagation delay instantaneously, was derived from satellite ranging method.

In [12], a power allocation policy was suggested to stabilize the system based on the amount of unfinished function in the queue form, and a routing solution was made for maximum total throughput. In[6], the problem of transmission power allocation, based on traffic demand for the multi-beam satellite communication systems was surveyed. In[12, 13], for satellite data communication systems, a new structure was provided which was adaptive in traffic demands for any satellite mobile users. A typical satellite systems was provided based on code division multiple access (CDMA) and frequency reuse techniques are presented in [14] . By analyzing the satellite capacity in this system model, it has been shown that the performance of this system is better than other satellite systems not using these techniques. In[7], the bandwidth allocation was provided to a trade-off between the maximum capacity and fairness among multi-beams. In[15], some new mathematical algorithms for a typical satellite system were provided based on beam hoping (BH) and deep packet inspection (DPI) algorithms to improve satellite capacity. In[16], an algorithm for power allocation, using a mathematical solution based on rain attenuation, was proposed. Therefore, it is only an algorithm was proposed without mathematic steps, and the appropriate allocation amongst the mobile users was also ignored.

In[17], joint optimum power and bandwidth allocation were surveyed in a typical satellite system. These schemes have tradeoff among different input parameters such as transmission power and the number of mobile users. This model has a new dynamic power allocation algorithm among mobile users with similar power in each beam. In[18], the optimal resource allocation for a satellite system is simulated based on the weather conditions such as rain attenuation. For multi-beam broadband satellites [19], a new model based on rain attenuation was provided. In [20], a new solution to allocate satellite bandwidth has been introduced based on multi-objective programming (MoP) optimization algorithm. For this kind of algorithm, space loss and satellite transmission power are two variables in bandwidth allocation which they can modelled through a group of objective functions. In [21], the optimization problem of power allocation for a satellite system was provided, which is shown to be convex. In this optimization problem, the Lagrangian multipliers were introduced, but an algorithm to extract the optimal Lagrangian multipliers was not presented.

In [6, 22], a joint power and bandwidth allocation algorithm to improve the total multi-beam satellite system capacity was formulated. In This paper, there is a solution for power allocation on the spot beams, without considering the power allocation to each mobile user in each beam. Therefore, it is important to determine how to allocate the power resources to the mobile users in each beam. Also, an optimal power allocation was provided in [23] to maximize the total capacity in the hybrid satellite-terrestrial network. The main problem is computed through the Shannon problem about capacity. Hence, the capacity not achieved in the real satellite communication. Although these references have addressed many resource allocations for a hybrid integrated satellite-terrestrial network, most of these works focus on the allocation a fixed bandwidth or power without considering the minimum and initial bandwidth for each beam. Therefore, there is not a novel approach for jointly optimization power and bandwidth allocated to each user in a hybrid integrated satellite-terrestrial network, according to the practical formula for calculating the allocated capacity for each user. Although these references have addressed many important challenges in space resource allocation, most of these papers are focused on the optimizing a specific utility function for each mobile user, according to the static power or bandwidth allocation for calculating the allocated capacity to each mobile user. Therefore, a novel approach for a dynamic bandwidth allocation based on two different types of values which include initial and required bandwidth is not considered to distribute the bandwidth allocation based on service level agreement (SLA).

A. Main contribution

Based on the above research, **firstly**, the main contribution of our paper is to provide a proposed system model which has multi-beam technology over satellite system to extend coverage and capacity, in a hybrid communication network with existing terrestrial infrastructures. This network has constraint in both transmission power and dynamic bandwidth allocation to dedicate mobile users. **Secondly**, the optimal transmit power and bandwidth allocation based on the extra bandwidth sharing problem is formulated as a convex optimization, according to the space propagation model, for a heterogeneous satellite network is defined to improve the throughput efficiency. **Thirdly**, the jointly optimum resource allocation which includes transmission power and bandwidth for each beam is obtained by using the dual Lagrange function. **Fourthly**, the allocated capacity of each beam is compared together under different circumstances, such as frequency reuse factor, digital modulation type, the number of beams and the number of mobile users in each beam. Also, based on the existing work in this proposed system model, the novel extra bandwidth sharing algorithm was provided for each beam which needs more bandwidth based on the SLA. This mathematical algorithm is a solution to dedicated bandwidth among mobile users in each beam based on dynamic resource allocation.

This paper is organized as follows. In Section II, a proposed heterogeneous satellite network is investigated. Section III provides jointly power and bandwidth allocation based on a mathematical algorithm to compute extra bandwidth among beams. Furthermore, Section V analyzes computational complexity based on the number of beams and mobile users, respectively. After that, simulation results are shown in Section VI. Finally, conclusion and future work are discussed in Section VII.

B. Acronyms

All of abbreviations which are applied in this paper are presented in Table.1.

II. SYSTEM MODEL

In this paper, a proposed heterogeneous satellite network which consists of a non-GEO satellite system, several beams with the number of mobile users are shown in Fig.1. Let

Table. 1. List of abbreviation words in this paper

Abbreviation	Explaniation
BH	Beam Hopping
CDMA	Code Division Multiple Access
DPI	Deep Packet Inspection
GEO	Geostationary
HSN	Heterogonous Satellite Networks
KKT	Karush-Kuhn-Tucker
MEO	Medium Earth Orbit
MMSE	Minimum Mean Square Estimation
NSR	Northern Satellite Research
PPP	Public Private Partnership
QoS	Quality of Service
SLA	Service Level Agreement
4G	Fourth generation
5G	Fifth generation

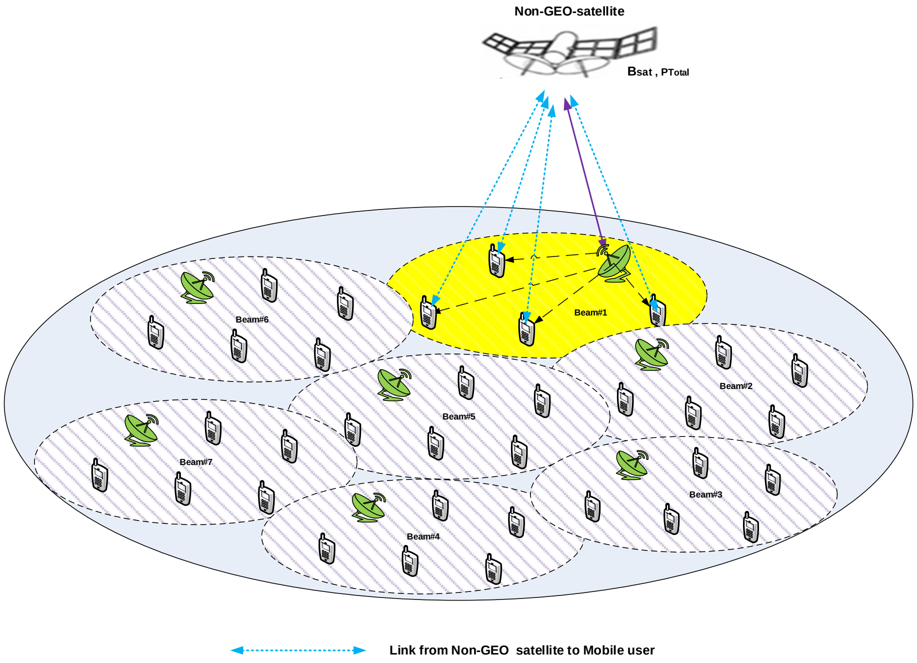

Fig 1. Heterogeneous satellite network.

k = (1…K) and n = (1…N) denote the number of beams and mobile users for each beam, respectively. Non-GEO satellite system is moving at tens of miles per second relative to the terrestrial equipment. Therefore, if there is a high speed for any non-GEO satellite system, Doppler frequency shift will cause. In this system model, we assumed that MEO satellite system has low speed over time in covered terrestrial territory. Therefore, Doppler frequency shift has negligible effect over space link budget.

A. Resource allocation algorithms

In this paper, there is a joint resource allocation for two important parameters in this system model which include power and bandwidth for mobile users in each beam, respectively. Therefore, there are two steps for this reason as follows:

1. There is a new extra bandwidth sharing algorithm which distributes based on comparison, initial and minimum required bandwidth among beams based on total satellite bandwidth.
2. Also, the initial power for each mobile user was uniformly distributed based on total satellite power (P_{Total}).

Based on space link budegt for any satellite system, the capacity of the kth beam (C(k)) is calculated according to the following equation (1)[24]:

$$C(k)=\sum_{n=1}^{N}C(n,k)=\frac{G(n,k)\times P(n,k)\times\left(\frac{G}{T}\right)(n,k)}{\mathrm{L}\times\left(\frac{E_b}{N_0}\right)(n,k)\times B}=\frac{\eta(n,k)\times B(k)}{\mathrm{F}\times(1+\alpha(n,k))}. \tag{1}$$

$$L=20\times\log(f_c)+20\times\log(h)+92.4+L_{Rain-att}.$$

In this equation, C (n,k) is the allocated capacity for the nth mobile user in the kth beam. All of abbreviations and notations which are applied in proposed system model and equations are presented in Table.2.

Also, is the spectral efficiency for the nth mobile user in the kth beam according to equation (2):

$$\eta(n,k)=\frac{r\times\log_2(M)}{1+\alpha(n,k)+\delta(k)\times B_{Total}}, \tag{2}$$

$$\delta(k)=\frac{B_{init}(k)}{B_{\min}(k)}.$$

In the above equation, r is the digital modulation rate, M is the digital modulation order, B_{Total} is the dedicated bandwidth for kth beam of satellite system in this system model and $\delta(k)$ is a portion of the B_{Total}. In this system model, we assumed that the kth beam must have a minimum bandwidth ($B_{min}(k)$).

Table. 2. List of required notations in equations

Parameters	**Explanations**
$G(n,k)$	Amount of satellite transmission antenna gain for the n^th^ mobile user in the k^th^ beam.
$P(n,k)$	Transmit power of the n^th^ mobile user in the k^th^ beam.
L	Free space loss
B	Boltzmann constant
B(k)	Dedicated bandwidth for the k^th^ beam
F	Frequency reuse factor for the n^th^ mobile user in the k^th^ beam.
$\left(\frac{G}{T}\right)(n,k)$	Gain-to-equvalent noise temprature ration for the n^th^ mobile user in the k^th^ beam.
$\left(\frac{E_b}{N_0}\right)(n,k)$	Enrgy to noise ratio for the n^th^ mobile user in the k^th^ beam.
$L_{Rain-att}$	Rain attenuation constant
$\alpha(n,k)$	Roll of factor

Also, proposed system model dedicates an initial bandwidth for the kth beam ($B_{init}(k)$) based on satellite bandwidth (B_{Sat}) which can be obtained according equation(3). It is important that B_{init} (k) maybe more or less than B_{min} (k).

$$B_{init}(\mathrm{k}) = \frac{B_{Sat}}{\mathrm{k}}. \tag{3}$$

Based on equation (1), the $B(k)$ is obtained as follows (4):

$$B(k) = \sum_{n=1}^{N} \frac{G(n,k)\times P(n,k)\times\left(\frac{G}{T}\right)(n,k)\times F\times(1+\alpha(n,k))}{\mathrm{L}\times\left(\frac{E_b}{N_0}\right)(n,k)\times B\times\eta(n,k)}. \tag{4}$$

III. A MATHEMATICAL ALGORITHM FOR EXTRA BANDWIDTH SHARING

In this system model, some beams may have extra bandwidth which no use in specific time. In this paper, we provide an algorithm to dedicate extra bandwidth to any beam which has not enough bandwidth to mobile users based on traffic demand in space service level agreement which space regulatory determines this kind of agreement. This new algorithm is known as an extra bandwidth sharing algorithm which is a very important problem in bandwidth

Table.3.Extra bandwidth sharing algorithm for the kth beam.

Steps	Explanations
1	Compute the required bandwidth for each beam (B(k)) based on equation (4).Then, we assumed that $B(k)= B_{init}(k)$
2	Compare between required bandwidth for each beam $B_{init}(k)$ and $B_{min}(k)$.
3	If $B_{min}(k)=B_{init}(k)$, then the required bandwidth for each beam (B(k)) is equal to $B_{init}(k)$ $B(k)= B_{init}(k)$; end
4	else if $(B_{min}(k) \leq B_{init}(k))$, $B_{add}(k) = B_{init}(k)-B_{min}(k)$; Then, B(k) is abstained as follows: $B_k = \frac{B_{init}(k)}{B_{init}(k) \times \frac{B_{add}(k)}{\sum_{k=1}^{K} B_{init}(k)}}.$ end

management in future satellite networks. In Table. 3, we show an algorithm to divide extra bandwidth among beams which have not enough bandwidth versus minimum required bandwidth.

IV. COMPUTATION JOINTLY OPTIMUM POWER AND BANDWIDTH ALLOCATION FOR EACH BEAM

In this system model, we assumed that the utility function is to minimize the sum of the squared difference between the total traffic demand and the capacity allocated to the nth mobile user. Therefore, the optimization problem is defined as an equation (5)[25]:

$$\text{Utility}(k) = \min_{P(n,k)} \sum_{n=1}^{N} (T_u(n,k) - C_u(\text{n},k))^2,$$
$$s.t. \begin{pmatrix} C_1 : \sum_{n=1}^{N} P(n,k) \leq P_{Total} \quad \forall k \\ C_2 : \sum_{n=1}^{N} B(n,k) \leq B(k) \quad \forall k \end{pmatrix}. \tag{5}$$

In the above equation, the allocated capacity to the nth mobile user should not exceed the traffic demand for the nth mobile user in the kth beam ($T_u(n,k)$), also it implies the constraint for total satellite power and the dedicated bandwidth of the kth beam (P_{Total}, B(k)), respectively. In (5), C_1 represents the power constraint for the nth mobile user for any beam ($\forall k \in K$). C_2 represents the bandwidth constraint for the nth mobile user for any beam ($\forall k \in K$). In equation (5), $P(n,k)$ is a target value and P_{Total} is a constraint in Lagrane function. Therefore, we can obtain the Lagrange function from the utility function for the nth mobile user in equation (6) as follows:

$$L(P(n,k),\lambda,\gamma(k)) = \sum_{n=1}^{N}(T_u(n,k) - C_u(\mathrm{n},k))^2 + \sum_k \lambda_k \times \left(\sum_n P(n,k) - P_{Total}\right) + \tag{6}$$
$$\sum_k \gamma(\mathrm{k}) \times (\sum_n B(n,k) - B(k)).$$

Where λ and γ(k) are the nonnegative Lagrangian multipliers that is associated according to constraints on (5).

Finally, the optimization problem with constraints can be obtained as follows:

$$F(\boldsymbol{\psi},\lambda,\gamma(k)) = \min_{P(n,k)} \max_{\lambda\geq 0,\gamma(k)\geq 0} L(P(n,k),\lambda,\gamma(k)), \quad \forall k \in K \tag{7}$$
$$\boldsymbol{\psi} = [P(n,1),P(n,2),......,P(n,K)].$$

***Lemma**: let's consider convex or concave for the objective function*

First of all, it must be determined whether the objective function $\mathrm{Utility}(k)$ for the nth mobile user is convex or concave. According to equation (8), second derivation of $\mathrm{Utility}(k)$ versus $P(n,k)$ is more than zero, it can be concluded that the objective function is a convex function [26].

$$\frac{\partial^2 L(P(n,k),\lambda,\gamma(k))}{\partial^2 P(n,k)} = -2 \times \frac{\partial^2 C_u(n,k)}{\partial^2 P(n,k)} \times (T_u(n,k) - C_u(\mathrm{n},k)) + 2 \times \left(\frac{\partial\, C_u(n,k)}{\partial\, P(n,k)}\right)^2 \geq 0,$$
$$\frac{\partial\, C_u(n,k)}{\partial\, P(n,k)} = \frac{G(n,k) \times \left(\frac{G}{T}\right)(n,k)}{\mathrm{L} \times \left(\frac{E_b}{N_0}\right)(n,k) \times B}, \tag{8}$$
$$\frac{\partial^2 C_u(n,k)}{\partial^2 P(n,k)} = 0,$$
$$T_u(n,k) - C_u(n,k) \geq 0.$$

Based on the description presented above, it is seen the utility function ($\mathrm{Utility}\ (k)$) is convex function and the minimization of convex function is convex optimization problem. Therefore, the Lagrangian method based on Karush-Kuhn-Tucker (KKT) condition can be used to solve the convex problem [26]. In this mathematical problem, the proposed resource allocation algorithm is based on the duality theory and nonnegative dual variables $(\lambda,\gamma(k))$. Based on equation (4), the required bandwidth for the nth mobile user is depending on the allocated power for the nth mobile user. Therefore, the optimum allocated power for the nth mobile user can result the optimum required bandwidth for the nth mobile user. Based on

KKT condition and Lagrangian function, optimized power allocation of the nth mobile user can be obtained easily from (9).

$$2\times\left(\frac{G(n,k)\times P(n,k)\times\left(\frac{G}{T}\right)(n,k)}{\mathrm{L}\times\left(\frac{E_b}{N_0}\right)(n,k)\times B}\right)\times \left(T_u(\mathrm{n},k)-\frac{G(n,k)\times P^{opt}(n,k)\times\left(\frac{G}{T}\right)(n,k)}{\mathrm{L}\times\left(\frac{E_b}{N_0}\right)(n,k)\times B}\right)= \lambda+\gamma(k)\times\left(\frac{G(n,k)\times\left(\frac{G}{T}\right)(n,k)}{\mathrm{L}\times\left(\frac{E_b}{N_0}\right)(n,k)\times B}\times\frac{(1+\alpha(n,k)+\delta(k)\times B_{Total})\times F\times(1+\alpha(n,k))}{r\times\log_2(M)}\right). \qquad (9)$$

Due to the concavity of the dual objective function, the Lagranigian multipliers, λ and γ can be obtained via a sub-gradient solution that is provided in (10):

$$\begin{pmatrix}\lambda^{j+1}\\ \gamma(k)^{j+1}\end{pmatrix}=\begin{pmatrix}\left[\lambda^{j}-\Delta_{\lambda}^{j}\left(\sum_{k}P(n,k)\le P_{Total}\right)\right]_0^{+}\\ \left[\gamma(k)^{j}-\Delta_{\gamma}^{j}\left(\sum_{k}B(n,k)\le B(k)\right)\right]_0^{+}\end{pmatrix},\forall k\in K. \qquad (10)$$

Where $[\ ]_0^x$ = max [11],j is the iteration value, Δ_{λ}^{j} and Δ_{γ}^{j} are the step size of iteration j ($j\in 1,2,....,J_{\max}$), $J_{\max}$ is the maximum number of iterations and the step size can be obtained according to the equation (11) [26-28].

$$\sum_{j=1}^{\infty}\Delta_{\lambda}^{j}=\infty,\lim_{j\to\infty}\Delta_{\lambda}^{j}=0,$$
$$\sum_{j=1}^{\infty}\Delta_{\gamma}^{j}=\infty,\lim_{j\to\infty}\Delta_{\gamma}^{j}=0. \qquad (11)$$

V. COMPUTATIONAL COMPLEXITY ANALYSIS

The sub gradient algorithm is useful for the problem that the dual function is not differentiable. This algorithm has been widely applied to solve the optimization problem [29, 30]. It has proven that the dual variables update algorithm is guaranteed to converge to the optimal problem as long as the iteration step size chosen is sufficiently small. A common criterion for choosing the iteration step size is that the step size must be square summable, but not absolute summable [29]. Since the utility function is convex, the sub-gradient method is utilized to solve it. Therefore, computational complexity is equal to $\mathrm{O}(N)$. Furthermore, substitute the values of the optimum power for each mobile user which is obtained into (9), and then update the Lagrange multipliers. In this step, computational complexity is equal to $\mathrm{O(K)}$. Finally, the total computational complexity of this system model is $\mathrm{O}(2\times K\times j+\mathrm{N}\times j)$, where j in equation (10), is the number of iterations [26]. It is important that j is independent of N and k. Therefore, the computational complexity of the proposed algorithms linear with both the numbers of the mobile users and beams.

VI. SIMULATION RESULT

We run the simulation results to demonstrate the effect of above proposed optimal power allocation and using the multi-beam in a heterogeneous satellite network. We assume that a satellite has 9 beams which have 5 mobile users in their coverage. Also, frequency reuse factor is 1, 2 and 4. For each spot beam, the initial dedicated bandwidth is 115(GHz). The transmission power of the high throughput MEO satellite is 45 (watt) in down link. Also, it is assumed that the values of free space loss, coding and modulation rate are the same for any beam. Also, we assumed that the step size of iteration j (Δ_{λ}^{j} and Δ_{γ}^{j}) for lagrange multipliers have initial value less than one. Some **simulation parameters** which are applied in proposed system model and equations in this paper are presented in Table.4.

A. Impact of the frequency reuse factor of each mobile user on the optimum capacity allocation

In this section, we assume that the allocated capacity between satellite beams has dynamic algorithm. Therefore, optimum capacity allocation between satellite beams is obtained by convex problems. As it is observed in Fig. 2, the capacity allocated is increased by increasing frequency reuse factor of the different numbers of beams. For example, when the frequency reuse factor increase from 1 to 4, capacity allocated decrease approximately from 6.5×10^{9} to 0.5×10^{9} while initial dedicated bandwidth is 115 GHz for each beam. In Fig. 3, Based on minimum mean square estimation (MMSE), it is obvious that the differential between simulation result value and initial traffic demand is low when the frequency reuse factor is 4.

Table. 4. Parameters of the system model (for the nth mobile user in the kth beam)

Definition Parameter	Value
Satellite frequency (f_c)	10-14 (GHz)
Distance satellite from earth	8000 Km
Beam number(1,....,K)	1,3,5 and 9
Mobile user number(1,......,N)	45
Traffic demand for each mobile user	1 to 45(Gbps)
Total satellite power(P_{total})	45 (Watt)
Satellite antenna gain(G_s)	40(dB)
Minimum bandwidth (B_{min})	28.5,57.5 and 115 (GHz)
Gain-to-equivalent noise temperature ratio for each beam (G/T)	20
Spectral efficiency of the coding and modulation mode (μ)	1.5
Roll-off factor the coding and modulation mode (α)	1
Energy to noise ratio (E_b/N_0)	2.63
Frequency reuse number (F)	1,2 and 4
Digital modulation type	QPSK
Light speed (C_0)	3×10^{8} (m/s)
Rain attenuation ($L_{rain-att}$)	3 (dB)
Boltzmann constant (B)	1.379×10^{-23}

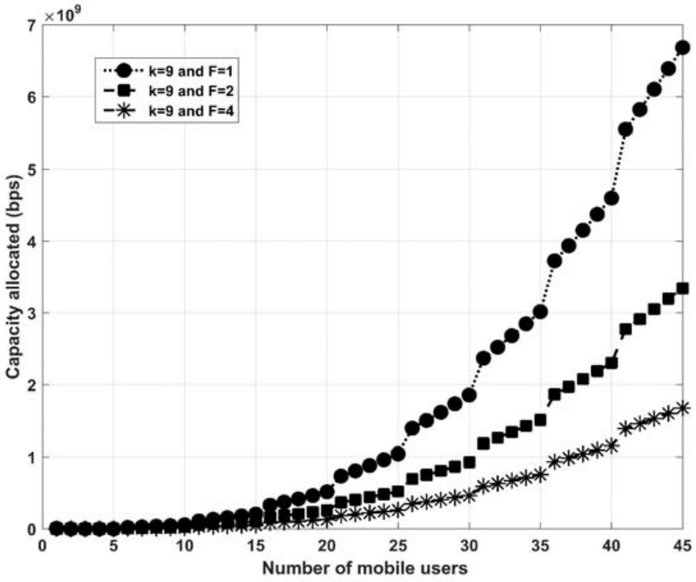

Fig. 2. Comparison of the optimum dynamic capacity based on frequency reuse factor

A. *Impact of the number of beams and mobile users on the optimum capacity allocated*

As it is observed in Fig.4, the optimum allocated capacity from [k=9 and N=5] to [k=3 and N=15] increase from 4.5×10^{9} to 9×10^{9}, when initial dedicated bandwidth is 115 GHz. In this simulation, the total number of mobile users is 45 in the coverage area for high throughput MEO satellite.

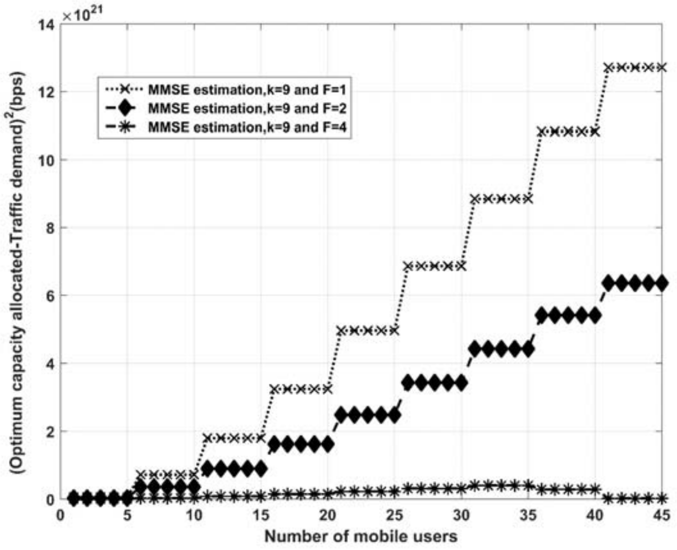

Fig. 3. Comparison of the squared difference (MMSE) between traffic demand and total optimum capacity.

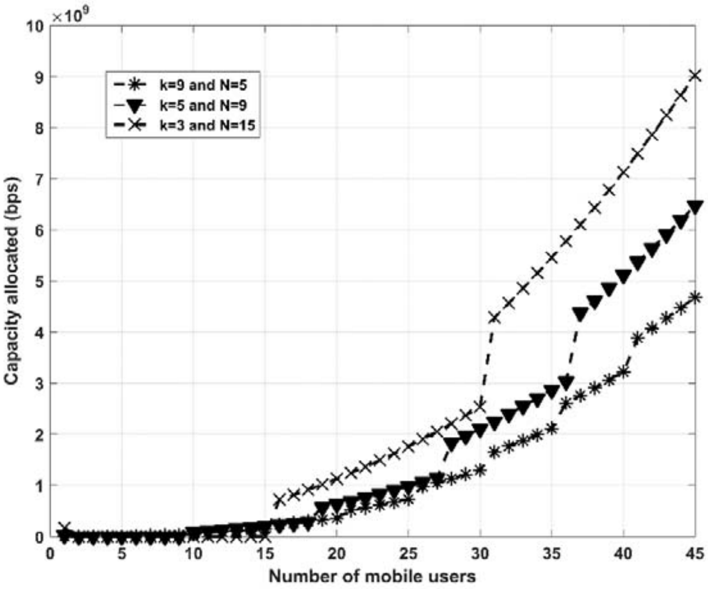

Fig.4. Comparison of the number of beams in terms of the optimum capacity allocated.

A. Impact of the rate and order digital modulation on the capacity allocated

It is seen from Fig. 5, the allocated capacity, is increased by increasing the order modulation. For example when the order modulation increase from 4 to 64, allocated capacity close to initial traffic demand. In this paper, the proposed algorithm provides more capacity to the mobile users with higher traffic demands. Otherwise, this type of algorithm decreases the capacity of each mobile user with lower traffic demands. For instance, In this figure, it is assumed that there is no capacity for the the five lowest traffic demand mobile users.

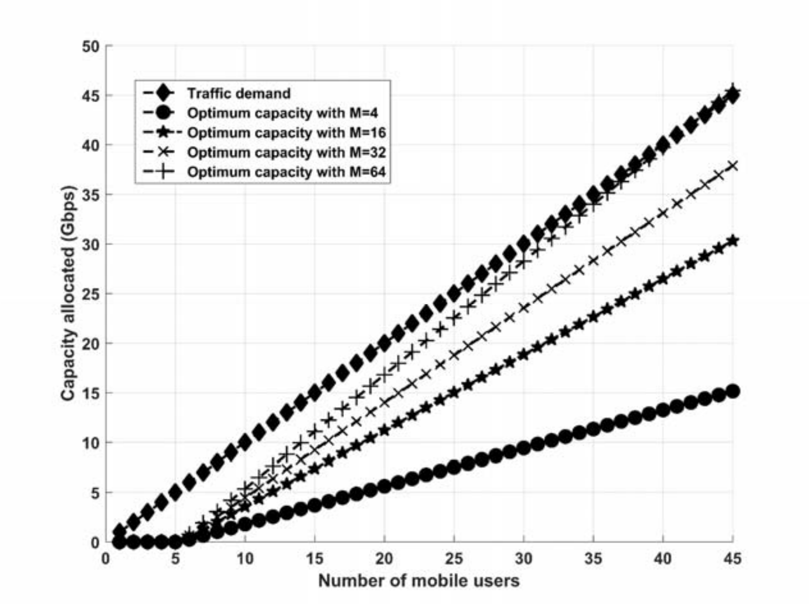

Fig.5. Comparison of the rate digital modulation in terms of the capacity allocated.

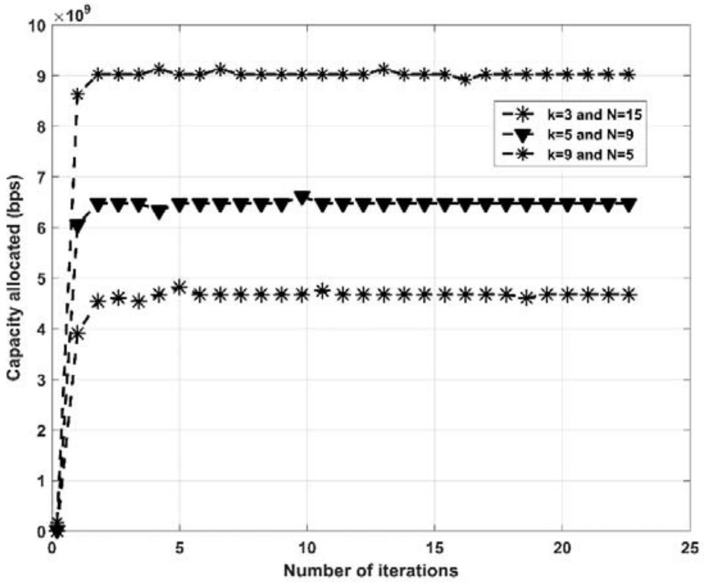

Fig. 6. The convergence in term the capacity allocated over the number of iterations.

A. Impact of the number of iteration on the capacity allocated

Fig. 6 shows the convergence in terms of the capacity allocated of each beam for the proposed system model versus the number of iterations. It can be observed that the proposed resource allocation takes nearly 21 iterations to converge to stable solutions. The number of iterations depends on the number of mobile users and the number of beams directly.

VII. THE CONCLUSION AND FUTURE WORKS

In this paper, the capacity allocation based on the dynamic allocation transmission power and bandwidth for each beam is analyzed in a typical heterogeneous satellite network which uses in future satellite communications. In the heterogeneous satellite network, it is important to improve the utilization spectral efficiency due to the scarceness resources such as power and bandwidth for each beam. To this end, the problem of dynamic resource allocation for future heterogeneous satellite network is mathematically formulated as a Lagrangian problem based on constraints. Also, in the optimal solution, the allocated capacity of each beam is obtained according to space propagation model. As a result, the allocated capacity based on the extra bandwidth sharing algorithm is more suitable for the practical satellite networks. Moreover, the computational complexity of the proposed algorithm is linear with both the numbers of the beams and number of mobile users. As a result, it can be implemented in the future satellite networks to provide non-delay-sensitive satellite services such as Fax and data when some terrestrial network cannot communicate with mobile users in some territory.

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