Analysis of Imperfect Space Channel for the Next Generation Satellite Networks

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Abstract

An efficient space data management is imperative in guaranteeing the best performance with a fair distribution of next generation satellite networks. Therefore, one of the major challenges to implement this kind of future satellite networks is evaluation any untrusted error for the best quality of service (QoS). In this regard, bit error rate (BER) criteria based on the type of space channel which it can be defined prefect or imperfect state between one or more satellites and terrestrial infrastructures seems to be an important subject for space communication. In this paper, the authors provide a bandwidth sharing algorithm for a proposed future heterogeneous satellite networks. This structure can have many satellites in different orbits beside terrestrial equipment having many antennas. In this paper to evaluate this system model, the coverage probability and space capacity based on input parameters such as path loss and signal to noise ratio (SNR) has been analyzed. Also, the bit error rate for a Multi-Input-Multi-Output (MIMO) satellite network based on imperfect channel estimation is simulated based on quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK) digital modulations which input parameters are error rate due to imperfect channel estimation and the number of antennas. Finally, two digital modulation compared together based on error rate changes.

Keywords: Satellite Communication; Small Cell; Frequency Reuse; Bandwidth Sharing; Imperfect Channel.

1. Introduction

Nowadays, There is a huge traffic demand from Very High Throughput Satellite systems (VHTS) to provide non delay sensitive services such as *Mobile-satellite* service having more secure and low delay based on new generation satellite networks such as fifth generation (5G) road map [1]. Most of space players have more endeavor to provide new space structures based on many satellites in different orbits look like satellite constellations along with terrestrial infrastructures look like base station which is well known Hybrid satellite-terrestrial networks to more coverage and capacity in anywhere and anytime[2]-[3]. This new structures in space part, has one or many satellites in different orbits such as low earth orbit (LEO) and medium earth orbit (MEO) which are called non-geostationary orbit (Non-GSO) or GEO that is called GSO. Based on orbital height, there are many opportunities to obtain efficiency in quality of space service. Moreover, this kind of structure can extend backhaul space services such as terrestrial mobile network. Thus, the integration of terrestrial infrastructures with many satellites in different orbits is attractive subject in future space research. With development Fifth Generation(5G), most of wireless communication systems expose with different challenges such as raising throughput and capacity, decreasing delay and latency, increasing coverage and reliability, causing seamless connection in anytime and anywhere based on 5G propagandas. In this reason, telecommunication industry must try to use satellite systems beside other infrastructures to provide more services to end space users [4]-[5].

Need for next generation satellite networks which have numerous antennas to communicate space data are very imperative in the development of space communication with the least error available due to environmental conditions in space channel between satellites and terrestrial equipment. To address this subject, several scenarios have been proposed based on space channel statistical status. One of them is perfect space channel which all of information in channel receiver is known [6]-[7]. A satellite system with prefect space channel has the following advantages based on the number of small cells:

1. The downlink and uplink power from the satellite is divided among small cells, and the bandwidth remains constant for each small cell. Ultimately, the total bandwidth increases as the number of small cells.

2. There will be a wide coverage by the satellite system following the replacement of several small cells [8].

In satellite systems with different antennas for the uplink or downlink, all of the receivers can be divided into small cells to take satellite services from one or many small cells with respect interference management among them. In this scenario, each antenna from the satellite can provide a suitable space link to each small cell which insert many users in them. Consequently, space industry needs a suitable solution to divide space resources

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between small cells which are covered by a satellite system [9]. In next generation satellite networks with long life time in space, it is very important to check the situation of traffic data between satellite and small cells based on resource conditions such as power and bandwidth. Therefore, a new algorithm is provided in [10], some new algorithm management for the provision of services is provided in [11]. Moreover, a new algorithm based on maximum/minimum signal to noise plus noise ratio and optimized data allocation is proposed in [12]. This algorithm can surmount the bit error rate of satellite systems when the number of antennas is increased on the side of the satellite or the side of the cell. To this end, it was analyzed and simulated based on the path loss factor. In [13], a solution for resource management based on the traffic level between the satellite system and the small cell was proposed. In [14], a new remedy for satellite systems was provided based on traffic demand. A new method based on frequency reuse in the achievement of high data rate in satellites was provided in [15]. In this paper, for a heterogeneous satellite network (HSN) having one or many satellites in different orbits, there is a line of side (LoS) space channel from any satellite to any terrestrial equipment which effects from space weather conditions. Firstly, based on environmental conditions may not be a prefect statistical status to evaluate performance space link. Secondly, space channel estimation for an imperfect space channel was computed to evaluate error level in each satellite system. For these evaluations, it is very important to evaluate a typical satellite network for the first step. Therefore, the main contribution in this paper is the introduction of a proposed model system which includes one or many satellite systems in different orbits beside terrestrial infrastructures such as ground stations providing based on the new bandwidth sharing algorithm. Also, the efficiency of the space link between satellites and ground stations for resource management which is critical point for this new kind of HSN is simulated by two types of digital modulation based on space recommendations. Finally, these digital modulations are compared with each other.

The rest of this paper is made up of the following sections. In Section II, the system model and the main formulations were proposed. In Section III, the new bandwidth sharing algorithm was supplied. In Sections IV, bit error rate equation based imperfect channels was computed. In Section V, simulation results based on proposed system model and desired input parameters were provided. Finally, Section VI, conclusion is drawn based on the research paper which is used MATLAB software for this reason.

2. Heterogeneous Satellite Network Model

The proposed heterogeneous satellite network is made up of two satellites, which have many antennas to transmit space (Orthogonal Frequency Division Multiple) OFDM data. In this paper, the effect of the enhancement of the number of antenna is taken into consideration. Consequently, M is the number of the transmitter's antennas at the side of the satellite(s) and N is the number of the receiver's antennas at the side of the small cell for any user. According to space requirement in (European Cooperation for Space Standardization) ECSS documents, the proposed system model was evaluated by using of two digital modulations which is known QAM and QPSK. Also, bit error rate was formulated by two digital modulations taking into consideration the space channel statistic status among satellite(s) and ground station(s). And finally, the estimation error was considered in the performance analysis of the proposed model system. In this system model is assumed, the satellite systems can be employed in GEO and LEO which are shown in Fig.1. In addition, the carrier frequency for this structure was assumed to be Ku, which is used to provide any space services. As seen in Fig.1, each satellite is supposed to has many antennas at the side of the satellite using to cover small cells. In this scenario, each antenna should have a minimum bandwidth to provide satellite service for any user in small cell.

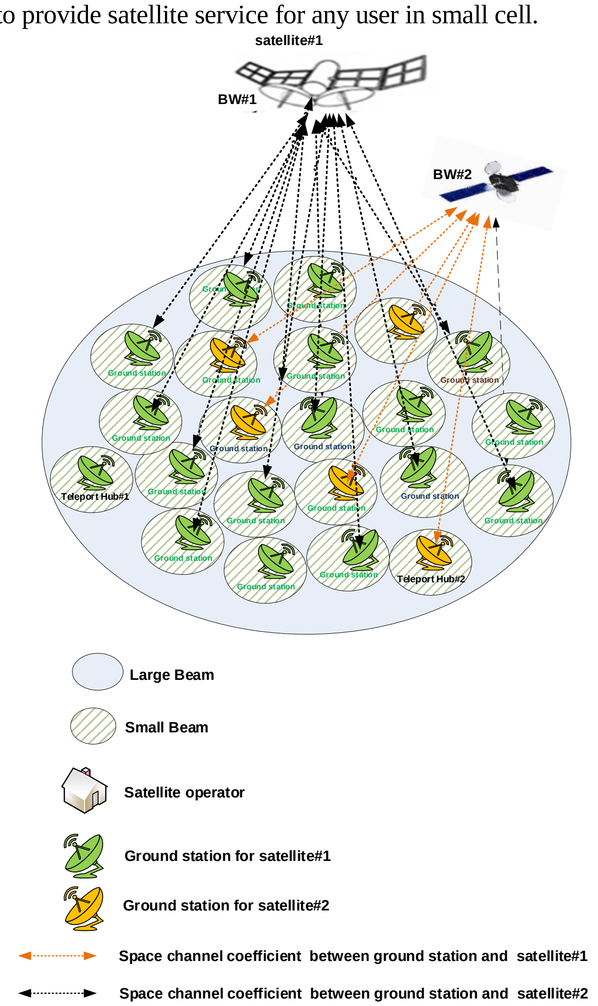

Fig. 1. Heterogeneous satellite networks

As well as, in each satellite system, one of the error criteria is the lack of communication data from satellite in a given small cell. So, there should be a specific benchmark to evaluate coverage area which it is important to dedicate different types of users such. For this reason, coverage probability (CP) of the satellite system was simulated as the SNR. Also, this parameter was found to be larger than a specific threshold level SNR with respect to the path loss factor e such as space weather conditions (rain attenuation) causing unsuitable condition (imperfect space channel) for satellite systems [16]. Note that the coverage probability is independent of the number of antennas on the side of the satellite or cell. When the threshold SNR is greater than the first value, coverage probability in closed form can be computed (1) [17]:

$$CP = \frac{e \times \sin(\pi / e)}{\pi \times SNR^{1/e}} \tag{1}$$

The coverage probability for each small cell in the satellite system is presented in Fig.2. In Fig. 2, path loss factor must be greater than the second value because the coverage probability in the satellite system has a better performance than the third and fourth 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.

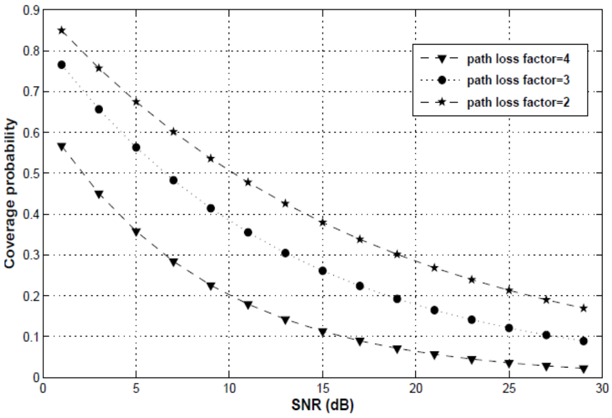

Fig. 2. Comparison of coverage probability versus different path losses.

3. A Mathematical Bandwidth Sharing Algorithm

Due to the increasing number of users to receive any satellite service especially in 5G road map, the Necessity of existence algorithms to resource managements such as power or bandwidth in these new types of satellite network seems to be important. In this regard, a bandwidth sharing algorithm is presented in this paper.

In this paper, we assumed that the minimum and initial bandwidth of the i[th] small cell for satellite system is $\mathbf{B_{min}}$ and $\mathbf{B_{initial}}$ based on space service level agreements (SSLAs). In addition, the total bandwidth for satellite was $\mathbf{B_{total}}$ and **K** was the number of small cell in the investigated scenario. Table I. shows a new bandwidth sharing formulation in the satellite system based on priority small cells which was specified in SSLA. In addition the bandwidth sharing management problem, frequency reuse factor is very important for designing satellite system to enhance capacity allocation.

Table 1. Bandwidth management HSN between small cells

```
clc
clearall
B_total = input('Total _bandwidth');
B_initial = input(' Initial _bandwidth');
B_min = input('Minimum _bandwidth');
if   B_total ≥ B_initial
B_extra =  B_total – B_initial ;
else if
B_extra  = 0;
end
end
If   B_min □  B_initial   # For each beam in satellite network
B'_min = B_min – B_initial ;   # Determination required bandwidth based on[B_min , B_initial]
end
B'_extra = B_extra − B'_min;   #  Evaluation the extra required bandwidth based on[B_extra , B'_min]
if   B'_extra ≥ 0
B'_initial = B'_extra + B_min ;
end
```

4. Bit Error Rate Computation Based on Imperfect Space Channel

As shown in Fig.1, on the basis of the prefect channel between satellite and ground cells, it was assumed that M-QAM and M-PSK had $\mathbf{M \times N + 1}$ degrees of freedom, where the weight is a function of the number of transmitter's antennas **M** on the side of the satellite and the number of receiver's antennas **N** on the side of the ground station. In this model of transmission, each antenna in two sides of model will be able to send or receive data to each other based on matrix formats. As a result, received signal R can be obtained by equation (2) which will be explained in the following. The prefect channel between the satellite and ground cell was modeled by a LoS channel and can be obtained by a matrix **H** with $\mathbf{M \times N}$ order and a zero mean and variance unit value. Each entry of matrix **H** is shown in $\mathbf{H}_{m\times n}$. $\mathbf{H}_{m\times n}$ represents the space channel gained between the m[th] receiver antenna at the side of the ground cell and the n[th] transmitter antenna at the side of the satellite. In addition, the received signal vector r can be given as [13], where $\mathbf{f_c}$ denotes the carrier frequency, C_0 is the speed of light, **d** is the distance between the transmitter antenna and receiver antenna and σ^2 is the additive white Gaussian noise. Moreover, the amount of rain attenuation was represented as $\mathbf{A_{Rain\ attenuation}}$ which was imposed to coverage probability, **S** is transmitter symbols based on matrix form from the side of the ground station and I is the unique matrix. Moreover, $a_{m\times n}$ denotes the space channel coefficients between the transmitter antenna and receiver antenna, which can be denoted as follows (2):

$$\mathbf{R}_{m\times1}=\mathbf{H}_{m\times n}\times\mathbf{S}_{n\times1}+\mathbf{n}_{m\times1},$$
$$\mathbf{H}_{m\times n}=\mathbf{a}_{m\times n}\times\exp\left(-j\times\frac{2\times\pi\times f_c}{C_0}\times d\right)$$
$$\times\exp\left(\frac{-A_{Rain-attenuation}}{10}\right), \quad (2)$$
$$\mathbf{a}_{m\times n}=\frac{C_0}{4\times\pi\times f_c\times d},$$
$$\mathbf{n}_{m\times1}=N(0,\sigma^2\times\mathbf{I}_{m\times1}).$$

In this formulation, some small cells had more bandwidth. Consequently, bandwidth management for capacity allocation is very important. In this section [19]-[21], by recognizing the space channel, the BER expression for M-QAM and M-PSK was formulated (3-4):

$$BER_{M-QAM}=\frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left(\frac{1}{2}\times(1-\mu_0)\right)^{N-M+1}\times$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_0)\right]^{K}+$$
$$\frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left[\frac{1}{2}\times(1-\mu_1)\right]^{N-M+1}\times$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_1)\right]^{K}, \quad (3)$$

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

Where 'μ_i' is as follow:

$$\mu_i=\sqrt{\frac{SNR\times\sin^2((2\times i-1)\times\pi/M)}{1+SNR\times\sin^2((2\times i-1)\times\pi/M)}}. \quad (5)$$

Unfortunately, in practice satellite systems, perfect channel may not be available. Consequently, the effect of channel error based on path loss on the performance of satellite networks must be investigated. This was achieved by modeling the estimation error as independent complex Gaussian random variables. In this paper, we estimated the imperfect space channel and surveyed the performance of receivers based on Zero Forcing (ZF) estimation algorithm. Also, all of BER formulations are obtained in closed-form.

Thereafter, the BER for satellite systems with M-QAM and M-PSK modulated signals were derived in the closed form. Based on assumption, the received signal vector r' can be written as:

$$\mathbf{r}'_{m\times1}=\mathbf{H}'_{m\times n}\times\mathbf{S}_{n\times1}+\mathbf{n}_{m\times1},$$
$$\mathbf{H}'_{m\times n}=\mathbf{H}_{m\times n}+\mathbf{e}_{m\times n}. \quad (6)$$

Now, we supposed that $\mathbf{H}'_{m\times n}$ is the non-suitable space channel, **n** is the white Gaussian noise and e is the path loss factor which is caused error in space link. This parameter does not correlate with $\mathbf{H}_{m\times n}$. The correlation coefficient ρ between the prefect and imperfect channels based on e is given by:

$$\rho=\frac{E\left(\mathbf{H}_{m\times n}-(\mathbf{H}_{m\times n}')^{*}\right)}{\sqrt{E\left[\mathbf{H}_{m\times n}{}^{2}\right]\times E\left[(\mathbf{H}_{m\times n}')^{*2}\right]}}=\frac{1}{\sqrt{1+\mathbf{e}^2}} \quad (7)$$

E(:) is statistical mean for each variable. Therefore, the SNR distribution based on e can be obtained as follows:

$$SNR(\mathbf{e})=\frac{SNR}{\left[1+(\mathbf{e}^2\times M\times s/\mathrm{E}\left(n^2\right)\right]} \quad (8)$$

By manipulation and making some changes in (9), the μ_i can obtain as follows:

$$\mu_i=\sqrt{\frac{SNR(\mathbf{e})\times\sin^2((2\times i-1)\times\pi/M)}{1+SNR(\mathbf{e})\times\sin^2((2\times i-1)\times\pi/M)}}. \quad (9)$$

5. Simulation Results

In this paper, in order to carry out the simulation process, a heterogeneous satellite network was provided. Also, to simulate input parameters of the system model were presented in Table 2. The allocated bandwidth of the i^th small cell with/without bandwidth sharing algorithm was compared as seen in Fig.3. As is clear, in some small cells such as third, sixth and eighth small cells, there is better performance because these small cells provide extra bandwidth to other small cells based on sharing bandwidth algorithm to allocate bandwidth properly which is provided in section III.

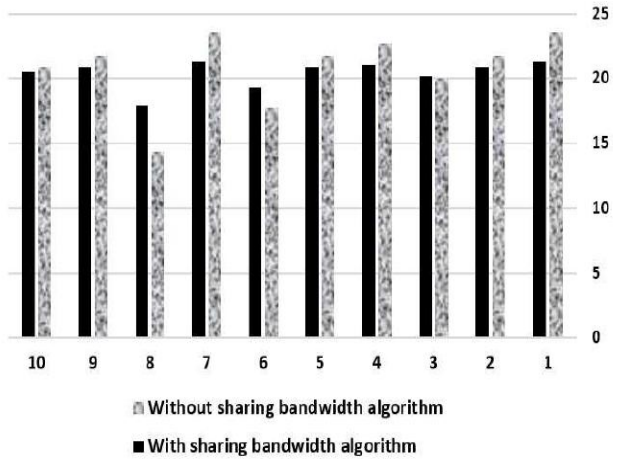

Fig. 3. Compare between with/without bandwidth sharing algorithms for the i^th small cell.

In Figs. 4 and 5, the BER performance of QPSK and QAM was investigated for imperfect channel with M= 4, N = 10 for e = [0; 10; 20; 30; 40; 50] percentages using the channel estimation error model in (9).

Table 2. Input Parameters of the HSN

Definition Parameter	Value
Satellite frequency (**f_c**)	11.0175 GHz-14.125 GHz
Distance satellite from earth (**d**)	36000 Km
Total Bandwidth of each small cell(**B_{Total}**)	530 MHz
Minimum Bandwidth of each small cell (**B_{min}**)	36 MHz
Initial Bandwidth of ten spot small cells(**B_{initt}**)	[36,45,55,40,45,72,36,106,45,50] MHz
Signal to Noise Ratio(**SNR**)	From 0 to 30 by 5 step size
Digital modulation type	QAM and QPSK
Number of small cells	10
Number of receiver antennas (**N**)	10
Number of transmitter antennas(**M**)	4

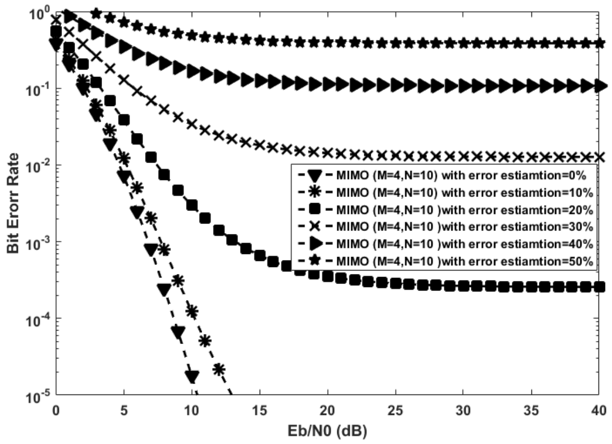

Fig. 4. BER performance of QPSK versus SNR (dB) based on path loss factor (e), [M=4, N = 10,8,6,4].

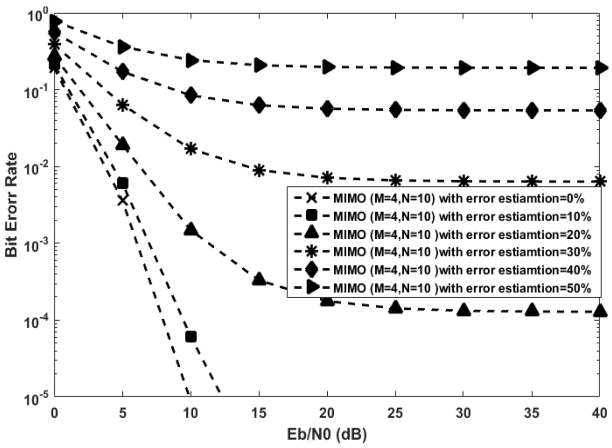

Fig. 5. BER performance of QAM versus SNR (dB) based on based on path loss factor (e), [(M=4, N = 10)].

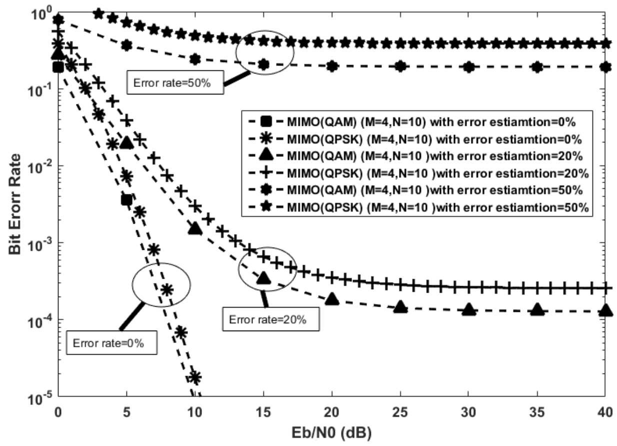

Fig. 6. Comparison BER between of QAM and QPSK versus SNR (dB) based on based on path loss factor (e), [(M=4, N = 10)].

As seen in these figures, it can be concluded that bit error rate increases with an increase in error estimation variance and QAM is better than QPSK based on the increase in the estimation error variance. Also, Under Consideration all the input parameters such as the number of antenna in satellite or ground station side, it can be concluded that the probability of BER in the QAM is less than QPSK.[20].

6. Conclusion

In this paper, first of all, a proposed HSN structure was provided which is considered by space industry to provide 5G requirements. In this way, a new algorithm to manage the space bandwidth in satellite systems was provided based on mathematical form. Also, based on space recommendations, HSN was simulated based on BER for both the QAM and QPSK digital modulation which is two types of recommended digital modulations in satellite systems. For this purpose, two perfect and imperfect space channels based on ECSS was compared together. As seen from the simulation results, an increase in the number of transmitter antennas in satellite systems precipitated an enhancement in capacity which is suitable to 5G road map. Furthermore, it should also be mentioned that the trade-off between the coverage probability and the BER of heterogeneous satellite network is important. Consequently, it is very important that next generation HSN has comprehensive review in space channel condition and resource management to reach high efficiency in future space telecommunication.

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