Capacity Saving Analysis of L_p-problem based Allocation with Packet Loss and Power Metrics in GEO-Satellite Communications Channels

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***Abstract*—This paper introduces a criterion, based on the L_p-problem, which has been employed to allocate capacity among Earth Stations. The obtained allocations permit a performance compromise between Packet Loss and Transmitted Power, which are taken into account as performance metrics. Moreover, starting from the proposed L_p-problem based allocation and considering specific analytical models for the Packet Loss Probability (PLP) and the Transmitted Power (TP), the paper highlights the existence of a Capacity Bound, independent of the overall capacity available C_{TOT}, on which the allocations converge. The main contribution of the paper concerns the performance analysis, carried out by simulation, which shows that the proposed method enables a significant savings of capacity and Transmitted Power and simultaneously, with only a limited worsening of the Packet Loss.**

Keywords-Satellite Communications; Multi-Objective Programming; Lp-problem based Allocation; Capacity Bound; Performance Analysis;

I. INTRODUCTION

Resource allocation in modern satellite networks, such as satellite-sensor [1], LTE [2] and WiMax [3], plays a crucial role and needs to be deeply investigated. In several previous works (such as [4], [5], [6] and [7]), we consider a scenario composed of a satellite communication system of Z earth stations that receive TCP traffic flows from a fixed number of sources and forward them onto a common geostationary satellite channel with an overall available capacity set equal to C_{TOT} [bps]. The channel state is modeled by considering the fading effect, due to atmospheric conditions, that have a negative impact on the quality of communications. As a consequence, to compensate, we apply a Forward Error Correction (FEC) encoding system, selecting the code rate as a function of the fading level F, expressed in [dB], undergone by each station. From the viewpoint of the higher protocol layers (i.e., above the network layer) the redundancy bits added to protect the transmitted information cause a reduction of the available capacity for transmission. Taking into account the proposed scenario, the problem considered in this paper is the well known capacity allocation problem. The goal is to share the channel capacity among the earth stations according to the policy defined in [6] whose performance is further analysed and discussed in this paper. The proposed allocation problem models each transmission entity (i.e., the Earth Stations) using some functions, which values are directly proportional to the capacity allocated, that represent some metrics that need to be optimized simultaneously (e.g., the Packet Loss Probability, shortly PLP, and the Transmitted Power, shortly TP, as done in this work). If the functions are in contrast to each other, as it happens in the case of this paper, the solution of the allocation problem must represent a compromise. For this reason we use the Multi-Objective Programming (MOP) framework to formulate the allocation problem thereby obtaining a solution also known as the Pareto Optimal Point (POP) set. To find out a single solution from this set, which is representative of the best compromise between the adopted metrics, we apply the L_p-*problem*.

An important consequence of the proposed approach is that its solution converges if C_{TOT} increases (i.e., the Capacity Bound (CB) discussed in [6]). It enables a significant capacity savings with respect to the allocation of the overall resources available on the channel: C_{TOT}. In fact, sharing all the channel capacity enables to optimize the value of a decreasing metric, however this is not true for an increasing metric. So it is useless to allocate the whole capacity but a significant portion can be reserved to increase the number of earth stations that can transmit on the satellite channel. It is worth noticing that all the stations, that are allowed to transmit, experience the same conditions in terms of PLP and TP.

The aim of this paper is to present a performance analysis of the allocation problem proposed, by focusing on the evaluation of the benefits obtained, considering the value of the PLP and the TP, with respect to the allocation of the whole available capacity C_{TOT}. Another key point of this paper is the evaluation of the increment of the number of earth stations computed by using a formula of the average number of earth stations, which can transmit with fixed value of PLP and TP, is presented.

As next step of the research presented in this work, adaptive modulation and coding techniques, applied together with the resource allocation, for example based on the DVB-S2 standard as in [8] and [9], will be object of thorough study. The rest of the paper is organized as follows. The next section presents a brief survey of the state of the art of resource allocation for satellite and wireless communications systems. In Section II the model adopted for the capacity allocation is presented while Section III describes the formulae employed for the Packet Loss Probability (PLP) and Transmitted Power (TP). Section IV presents the simulation results that highlight the advantages obtained allocating a capacity equal to the CB, obtained by using our allocation method with respect to the allocation of the overall available capacity. Finally Conclusions are drawn.

II. THE FORMULATION ALLOCATION PROBLEM

The model adopted in this paper and developed in previous works by same authors ([5] and [6]), is based on three different components. The physical entities represent the earth stations, which are composed by different queues called virtual entities. Each queue is characterized by several objective function that model some performance metrics such as the Packet Loss Probability and the Transmitted Power, as done in this work.

A. The MOP based capacity allocation problem

To formalize the MOP based capacity allocation we define two vectors: the first one, reported in (1) is the control vector and contains all the capacities allocated to each virtual entity for each physical entity considered. Formally we consider that each physical entity is identified by $z \in [1, Z]$. Y_z is the number of virtual entities of the $z-th$ physical entity. Each virtual entity is identified by $y_z \in [1, Y_z]$. M_{y_z} is the number of objective functions for each virtual entity y_z. Each objective function, of a given $y_z - th$ virtual entity, is identified by the index $m \in [1, M_{y_z}]$. C_{y_z} is the capacity allocated to the virtual entity y of the physical entity z

$$\mathbf{C} = (C_{1_1}, C_{2_1}, C_{3_1}, ..., C_{Y_1}, ..., C_{1_Z}, C_{2_Z}, C_{3_Z}, ..., C_{Y_Z}) \tag{1}$$

In this work the capacity allocation is supposed to be carried out in a centralized fashion: the control vector is the output of a centralized decision maker and represents the decision taken by the allocation algorithm, that is the capacity assigned to each queue in each earth station. It is worth noticing that the overall capacity allocated to the $z-th$ physical entity, C_z is the sum of the capacities allocated to all its virtual entities that are $C_z = \sum_{y=1}^{Y_z} C_{y_z}$.

The second vector defined is the so called objective function vector and contains the value of each objective function of each virtual entity in each physical entity. All the components of this vector are the metrics, the PLP and the TP analytically defined in Section III that need to be optimized simultaneously.

$$\begin{aligned}\mathbf{F}(\mathbf{C}) = (&F_{1,1_1}(\mathbf{C}), ...\\ &F_{M_{1_1},1_1}(\mathbf{C}), ..., F_{1,Y_Z}(\mathbf{C}), ..., F_{M_{Y_Z},Y_Z}(\mathbf{C}))\end{aligned} \tag{2}$$

In (2), the generic term $F_{m,y_z}(\mathbf{C})$ is the $m - th$ objective function of the $y - th$ virtual entity of the $z - th$ physical entity. Considering the Multi Objective Programming theory formalized in [5] with the control vector defined in (1) and the objective function vector (2) is possible to formalize the MOP based capacity allocation problem as follows:

$$\begin{cases} \mathbf{C}_{opt} = \Big(C_{1_1,opt}, C_{2_1,opt}, .., C_{Y_1,opt}, .., \\ C_{1_Z,opt}, C_{2_Z,opt}, .., C_{Y_Z,opt} \Big) = \arg\min_{\mathbf{C}} \mathbf{F}(\mathbf{C}); \\ C_{y_z} \geq 0, \forall y_z \in [1, Y_z]. \forall z \in [1, Z] \\ \sum_{z=1}^{Z} \sum_{y=1}^{Y_z} C_{y_z} \leq C_{TOT} \end{cases} \tag{3}$$

An important boundary is imposed in (3): the sum of the capacity allocated to each virtual entity must be lower or equal to the overall capacity available in the channel C_{TOT}. As a consequence the MOP capacity allocation problem determines a feasibility region that contains all the control vector that may be admissible solutions. The goal of this allocation policy is to determine a control vector C_{opt} that simultaneously minimizes all the components of the objective function vector.

The solution of the defined problem is not single but it is a set, called Pareto Optimal Points (POP) set. The position of this set depends on the characteristics of the objective functions considered: if all objective functions are strongly decreasing [10], then a solution $\mathbf{C}_{opt}$ is a POP if and only if the solution is on the constraint boundary $\sum_{z=1}^{Z} \sum_{y=1}^{Y_z} C_{y_z} = C_{TOT}$. If this condition is not true the POP set may also stay also inside the feasibility region which means that the Pareto Optimal may also be a point for which $\sum_{z=1}^{Z} \sum_{y=1}^{Y_z} C_{y_z} < C_{TOT}$.

The strongly decreasing assumption concerning the objective-function vector is quite typical because common performance functions applied in telecommunication networks such as Packet Loss Probability, Packet Delay and Packet Jitter are quantities that decrease their values when the allocated capacity value increases. This is not true if other important metrics are also used: power, but also processing and computation effort. In those cases, as done in this paper considering the PLP as one of the adopted metrics, the allocation of the overall available capacity C_{TOT} may not be the optimal choice. In fact as previously said the optimal solution may also be also inside the feasibility region and not on the constraint boundary. The aim of this paper is to identify a solution through the MOP approach, as well as to compare the performance by way of the results obtained sharing the overall capacity available among the considered earth stations.

B. The L_p-problem based capacity allocation

As previously said, the MOP based capacity allocation problem determines as a solution a set of points. In this paper we apply the L_p-problem to obtain a single control vector that represents a compromise between the adopted metrics. The idea is to allocate capacity so that the value of each objective function is as close as possible to its ideal value. The set of ideal capacities (i.e. the ideal vector (4)) is composed of the ideal decision variable vector elements $C_{y_z,id}^{F_{k,y_z}}$ for which F_{k,y_z} attains the optimum value

$$\begin{aligned}&\mathbf{C}_{id}^{F_{k,y_z}} = \Big(C_{1_1,id}^{F_{k,y_z}}, C_{2_1,id}^{F_{k,y_z}}, ..., C_{Y_1,id}^{F_{k,y_z}}, ...,\\ &C_{1_Z,id}^{F_{k,y_z}}, C_{2_Z,id}^{F_{k,y_z}}, ..., C_{Y_Z,id}^{F_{k,y_z}}\Big) = \arg\min_{\mathbf{C}} F_{k,y_z}(\mathbf{C});\\ &\forall k \in [1, M_{y_z}], \forall y_z \in [1, Y_z], \forall z \in [1, Z]\end{aligned} \tag{4}$$

Each element $C_{y_z,id}^{F_{k,y_z}}$ can assume a value between 0 and C_{TOT}, independently of any physical constraint and of the values of the other components of vector (4). It is called ideal (utopian) for this reason. For example, if a generic objective function is decreasing versus the allocated capacity, it is obvious that it is ideal to use all the possible capacity C_{TOT}, while if it is increasing versus capacity, it is ideal allocating no capacity at all. The values of vector (4) are considered known in the remainder of the paper while the vector in (5) contains each objective function attaining its ideal value.

$$\begin{aligned}\mathbf{F}_{id} = \bigg(&F_{1,1_1,id}\Big(\mathbf{C}_{id}^{F_{1,1_1}}\Big), .., F_{k,y_z,id}\Big(\mathbf{C}_{id}^{F_{k,y_z}}\Big), ..,\\ &F_{M_{Y_Z},Y_Z,id}\Big(\mathbf{C}_{id}^{F_{M_{Y_Z},Y_Z}}\Big)\bigg)\end{aligned} \tag{5}$$

To compute the distance to the ideal vector we apply the generic norm p and in (6) and in (7) is reported the formulation of the L_p-problem based capacity allocation (L_pCA)

$$\begin{aligned}&\mathbf{C}_{all} = (C_{1_1,all}, C_{2_1,all}, ..., C_{Y_1,all}, ..., C_{1_Z,all}, C_{2_Z,all}, ...,\\ &C_{Y_Z,all}) = \arg\min_{\mathbf{C}\subset\mathbf{C}_{opt}} J_p(\mathbf{C})\end{aligned} \tag{6}$$

where $J_p(\mathbf{C})$ is a function representing the generic norm, usually indicated with the symbol L_p [10]:

$$\begin{aligned}J_p(\mathbf{C}) = \Bigg(&\sum_{z=1}^{Z}\sum_{y=1}^{Y_z}\sum_{k=1}^{M_{y_z}} w_{k,y_z}\bigg|F_{k,y_z}(\mathbf{C}^{F_{k,y_z}})+\\ &- F_{k,y_z,id}\Big(\mathbf{C}_{id}^{F_{k,y_z}}\Big)\bigg|^{p}\Bigg)^{1/p}\end{aligned} \tag{7}$$

and $\sum_{k=1}^{M_{y_z}} w_{k,y_z} = 1$, $w_{k,y_z} > 0, \forall k \in [1, M_{y_z}]$, $\forall y_z \in [1, Y_z], \forall z \in [1, Z]$ so to assure the Pareto optimality of the solution. Modifying the values of the weights it is possible to differentiate the importance of the considered objective functions. As a consequence, the proposed capacity allocation is elastic and can be applied to different scenarios with heterogeneous traffic flow with different QoS requirements (e.g., telephony, videoconferencing, audio/video streaming, web transactions).

The most interesting contribution of this work, that is a consequence of the allocation method proposed, concerns a comprehensive analysis of the performance assured by the existence of a Capacity Bound, that has been demonstrated in [6]. This point represents a Pareto Optimal Point (POP) on which the L_pCA problem converges. It implies that, from the practical viewpoint, a Satellite Service Provider may provide capacity allocations to all the entities involved in the allocation process without employing the overall available capacity. It allows dedicating the rest of the capacity to further possible entities. As shown in Section IV, moreover, it can be done without penalizing the overall performance and without capacity wasting.

III. THE OBJECTIVE FUNCTIONS

In this paper each physical entity represents an Earth Station that transmits through a satellite channel and is composed by a single queue (as a consequence, physical and virtual entities are not differentiated). Each considered entity is represented by two objective functions that are the Packet Loss Probability, shortly PLP, due to congestion ($F_{1,1_z} = P_{loss_z}(C_z)$) and the Transmitted Power, shortly TP, ($F_{2,1_z} = W_{tx_z}(C_z)$) and the constrain is defined by the amount of available capacity ($\sum_{z=1}^{Z}\sum_{y=1}^{Y_z} C_{y_z} \leq C_{TOT}$).

A. Packet Loss Probability Function

The PLP model used in this paper is referred to the loss due to congestion for a Transmission Control Protocol (TCP) based traffic flow and is analytically reported in (8):

$$P_{loss_z}(C_z) = \frac{k_z \cdot N_z^2}{(\frac{R_z \cdot C_z \cdot rtt_z}{l} + Q_z)^2} \tag{8}$$

It is worth noticing that the PLP model adopted in this work is a decreasing function with respect to the allocated capacity C_z. Moreover in this paper, the values of the parameters reported in (8), applied in the performance analysis section, and the related meanings are: k_z=128/81 is a constant depending on TCP protocol, N_z =10 is the number of active TCP connection for the *z-th* station, Q_z is the buffer size, equal to 10 packets, for the *z-th* station. rtt is the round trip time, equal to 512 [ms], l =1500 [byte] is the TCP packet size and R_z and C_z are the code rate and the capacity allocated to the *z-th* station, respectively. Channel conditions vary over the time and, in this paper, the undergone fading level F_z for each station represents the satellite channel status. Each Earth Station is supposed to apply different code rates in dependence on the channel status modeled considering the fading level. Code rates are assigned as in Table I. This hypothesis allows considering packet losses due to congestion because channel errors are made negligible by

TABLE I: APPLIED CODE RATES

F_z $[dB]$	0.0 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 - 4.0	4.0 - 5.0
R_z	7/8	5/6	3/4	2/3	1/2

applying encoding. On the other hand, as previously said, from the application layer view point, represents a reduction in the available capacity for the considered station. So the detriment of the channel conditions due to the fading effect is modeled by a reduction of the capacity available to a station with respect to the portion allocated as reported in equation (8) where the applied code rate is the capacity reduction factor.

B. *Transmitted Power Function*

The TP of the *z-th* station is reported in (9):

$$TP_z(h_z, C_z) = (2^{\frac{C_z}{W}} - 1) \cdot \frac{1}{h_z} \tag{9}$$

Considering the formulation of the TP is possible to view that it is an increasing function with respect to the allocated capacity C_z. h_z, called link constant in this paper, takes into account the parameters related to the satellite link. In more detail, it contains the transmission antenna gain G_{T_z} of the *z-th* station, the receiver antenna gain on the satellite G_R (common for each station) both equal to 10^4, the Boltzman constant *k* equal to $1.38{\cdot}10^{-23} J{\cdot}K^{-1}$, the noise temperature *T* set to 290 [K] (considering additive white Gaussian noise), the bandwidth of the satellite channel *W*=1 [MHz] and the Free Space Loss (*FSL*) set equal to 10^{19} as defined in [11]. In practice, the coefficient $\frac{1}{h_z}$ is:

$$\frac{1}{h_z} = \frac{k \cdot T \cdot W \cdot FSL}{G_{T_z} \cdot G_R} \tag{10}$$

The Transmitted Power function is obtained by combining two equations: $C_z = B \cdot log_2\Big(1 + \Big(\frac{C}{N}\Big)_z\Big)$ the Hartley-Shannon law, and $\Big(\frac{C}{N}\Big)_z = \frac{G_{T_z} \cdot G_R \cdot TP_z}{k \cdot T \cdot B \cdot FSL}$ that represents the carrier to noise ratio [11].
It is worth noticing that the employment of equation (9) as transmitted power function implies the hypothesis that the transmission bit rate of the $z-th$ station is equal to the allocated capacity C_z. Both the objective functions considered in this paper are continuous and differentiable in $\mathbb{R}$ so assuring the existence of a solution of the L_p-problem applied.

C. *The Capacity Bound*

In this paper we consider Z physical entities, a single virtual entity for each physical entity ($Y_z = 1\,\forall z \in [1, Z]$) and two objective functions for each virtual entity ($k = 2\,\forall y_z \in [1, Y_z], \forall z \in [1, Z]$). Considering the two objective functions previously introduced, the vector $\mathbf{F}(\mathbf{C})$, defined in (2) it is possible to define a capacity bound where our allocation converges. In practice, given fixed channel conditions, if the overall capacity available for the entire communications system significantly grows, the POP solution provided by solving (3), considering $J_p(\mathbf{C})$ as defined in (7), will not significantly change tending, in the sense of a horizontal asymptote, to a quantity called Capacity Bound C^{bound}. From a formal viewpoint,

$$C^{bound} = \sum_{z=1}^{Z} C_z^{bound}, C^{bound} < C_{TOT} \tag{11}$$

where C_z^{bound} is the portion of capacity allocated to the $z - th$ Earth Station when the overall allocation converges on the defined bound. The mentioned C^{bound} exists and is finished if $C_z^{bound}\ \forall z \in [1, Z]$ is a quantity independent of C_{TOT} when C_{TOT} tends to infinity. [6] defines three conditions, regarding the objective functions used, that assure the existence of the capacity bound. Moreover it demonstrates also that the proposed L_pCA, with the considered metrics, satisfies these conditions.

IV. PERFORMANCE ANALYSIS

The scenario considered in this performance evaluation has been implemented through the *ns-2* simulator. It is composed by $Z = 2$ Earth Stations that transmit TCP traffic over a common geostationary satellite channel. The overall duration of the simulation is 300 [s]. The allocation is done each 5 [s] (i.e., allocation period) and the Fading Level suffered by each $z - th$ station, expressed by F_z, assumes values, kept constant in each allocation period, that belong to Table I. It is worth noticing that F_z is not included in (10) because the fading is supposed to be compensated applying the FEC encoding. As a consequence the terms F_z does not modify the value of TP, which depends only on the *FSL*.
The main contribution of this section is the investigation of the advantages of the proposed L_pCA approach in terms of saved capacity, which are strictly related to the existence of the Capacity Bound. In more detail, the performed tests consider the two earth stations with a random fading level considered uniformly distributed among all possible levels and the code rate is consequently chosen according to the aforementioned table. Obviously, the fading level value is considered known when the allocation algorithm acts. Each value of the performance metrics reported in the figures below represents the average of the values obtained by a number of simulation runs aimed at guaranteeing a confidence interval of the 95%.
The Transmitted Power [W] (TP) values, reported in the following figures, are computed through the objective function (9) itself on the basis of the allocated capacity C_z; the packet loss has been computed, for each allocation period, as the number of packets lost for congestion over the number of sent packets, measured through

the available *ns-2* simulation counters. For this reason, in the following, the results are presented in terms of Packet Loss Rate (PLR). Five weighs configurations are applied to give more, or less, importance to an objective function with respect to the other for both the stations ($z = 1$ and $z = 2$): $w_{1,1_z}$=0.1 and $w_{2,1_z}$=0.9; $w_{1,1_z}$=0.25 and $w_{2,1_z}$=0.75; $w_{1,1_z}$=0.5 and $w_{2,1_z}$=0.5; $w_{1,1_z}$=0.75 and $w_{2,1_z}$=0.25; $w_{1,1_z}$=0.9 and $w_{2,1_z}$=0.1.

The practical purpose of this section is to explicitly evaluate the ratio between the obtained capacity allocations and the related performance with L_pCA, which operates at the C^{bound} value, and the reference case in which the overall capacity C_{TOT} is employed.

To reach the aim, we define the quantity, C_z^{ref}, for the $z-th$ station, which represents the capacity allocated to the $z-th$ station according to its channel condition, applying the L_PCA and imposing that the overall capacity is used, in practice $\sum_{z=1}^{Z} C_z^{ref} = C_{TOT}$. Similarly, the quantity $PLR_z(C_z^{ref})$ and $TP_z(C_z^{ref})$ are, respectively, the Packet Loss Rate and the Transmitted Power of the $z-th$ station obtained allocating to it C_z^{ref}.

In this work we define the *Capacity Saving Ratio* (C_{SR}) as the quantity reported in (12), which is the percentage of the capacity saved using C^{bound} (i.e., to employ C_z^{bound} for the $z-th$ station), with respect to the overall capacity available, C_{TOT} (i.e., to employ C_z^{ref} for the $z-th$ station):

$$C_{SR} = \frac{\left|C^{bound} - C_{TOT}\right| \cdot 100}{C_{TOT}} \tag{12}$$

In the same way, we define the *Transmitted Power Saving Ratio* (TP_{SR}) as the percentage of the average TP saved with respect to the TP obtained sharing the overall available capacity: (13).

$$TP_{SR} = \frac{\left|\sum_{z=1}^{Z} \left(TP_z(C_z^{bound}) - TP_z(C_z^{ref})\right)\right| \cdot 100}{\sum_{z=1}^{Z} TP_z(C_z^{ref})} \tag{13}$$

Similarly, the *Packet Loss Rate Increasing Ratio* (PLR_{IR}) is defined as the percentage of PLR increase obtained allocating C_z^{bound} to the $z-th$ Station with respect to the PLR obtained allocating the overall capacity among the station:

$$PLR_{IR} = \frac{\left|\sum_{z=1}^{Z} \left(PLR_z(C_z^{bound}) - PLR_z(C_z^{ref})\right)\right| \cdot 100}{\sum_{z=1}^{Z} PLR_z(C_z^{ref})} \tag{14}$$

The defined metrics are reported in figures 1, 2 and 3. In all cases, the advantage of the L_pCA employment is clear and very satisfactory.

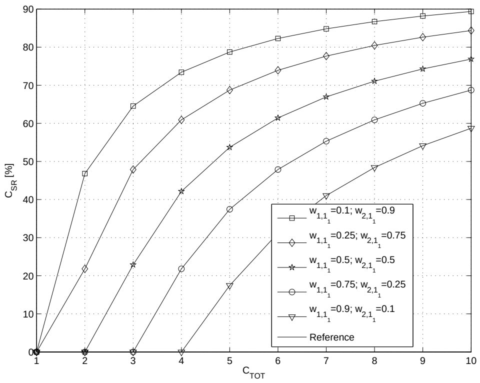

Figure 1: Capacity Saving Ratio using L_pCA.

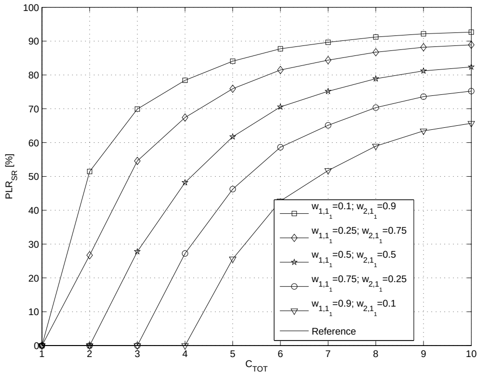

Figure 2: Packet Loss Rate Increasing Ratio using L_pCA.

A further consequence of the capacity saving obtained with the L_pCA is the possibility to serve other stations with the same channel, without the necessity of increase the C_{TOT} and, simultaneously, without a degradation of the performance in terms of PLR and TP. Obviously, the number of stations depends on their channel condition but it is possible to compute the average number as we define in the following:

$$N(C_{TOT}, C^{bound}, Z) = \left\lfloor (C_{TOT} - C^{bound}) \cdot \frac{Z}{C^{bound}} \right\rfloor \tag{15}$$

where Z are the Earth Stations that transmit traffic over the satellite link, and N is the number of Earth Stations that can be served with the same channel. In equation (15) the average increase of Earth Station number N is calculated as the inferior integer part of the product between the capacity saving obtained applying the L_pCA given by ($C_{TOT} - C^{bound}$) and the inverse of the average capacity allocated to a single station (i.e., $\frac{Z}{C_{TOT}}$). Obviously, this quantity increases if the overall capacity (C_{TOT}) increases or if the allocated capacity (C^{bound}) decreases.

In Figure 4 is reported the average increase of the number of Earth Stations $N(C_{TOT}, C^{bound}, Z)$ that can transmit on the satellite channel. In this case Z is set equal to 2, C_{TOT} varies in the range $[1-10]Mbps$.

V. CONCLUSIONS

The work extends the capacity allocation method proposed in [5] modeled as the MOP problem. In particular, a criterion based on the L_p-problem is proposed to find out a capacity allocation, among Earth Stations, representative of a compromise if Packet Loss Probability (PLP) and Transmitted Power (TP) are taken into account as performance metrics. Moreover, applying the proposed L_p-problem based allocation and considering PLP and TP analytically modeled as in Section III, the obtained allocations converge on a Capacity Bound. This bound is independent of the overall capacity available C_{TOT}. The performance analysis shows that the proposed method enables a significant capacity and TP saving and, simultaneously, a limited worsening of the packet losses. From the practical viewpoint, the paper contribution implies that a Service Provider may provide capacity allocations to Z Earth Stations without employing its overall available capacity and may dedicate the rest of it to other possible entities without penalizing the overall performance and avoiding capacity wasting.

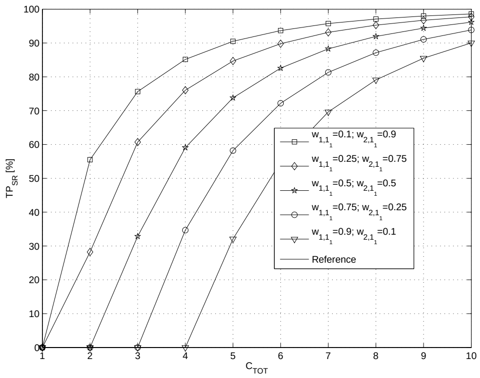

Figure 3: Transmitted Power Saving Ratio using L_pCA.

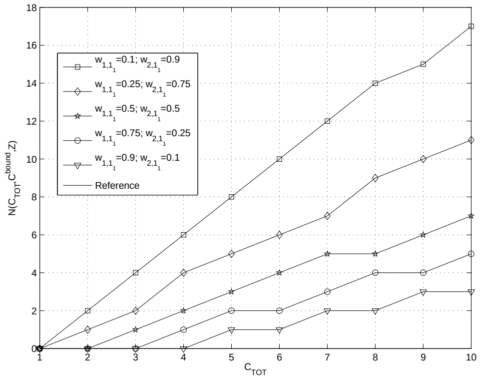

Figure 4: Average increasing of the number of Allowed Earth Station using L_pCA.

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