Abstract – The paper formalizes the bandwidth allocation process over space communication systems as a Multi – Objective Programming (MOP) problem and proposes an allocation scheme based on the GOAL programming called “Minimum Distance” (MD) algorithm. The method is aimed at following the performance obtained by each station when there is no conflict among the stations to access the channel. In short, the algorithm assigns the bandwidth so to approach a non-competitive situation as close as possible. It is tested over a faded channel by using only TCP/IP traffic. The performance evaluation is carried out analytically by varying the degradation level of the channel and the traffic load offered to the earth stations, taking High Amplitude Platforms (HAPs) as technological reference.

Keywords – Space Communications, Dynamic Bandwidth Allocation, Multi-Objective Programming, Performance Evaluation.

I. INTRODUCTION

The advantage of using space communication systems (HAPs [1], GEO and LEO satellites, possibly integrated with terrestrial links) for TCP/IP applications is clear: to exchange ubiquitous information among geographically remote sites also in hazardous areas with large bandwidth availability. In such environments one of the main cause of degradation is rain attenuation, which generates significant communication deterioration, information loss and, consequently, QoS degradation. Allocating the bandwidth properly among the earth stations (which can be affected by different fading level) is topical to mitigate the problem and to increase the provided QoS among the stations connected through a space connection. The choice of the technology does not affect the general behaviour of the scheme and it has been left unspecified here for the sake of generality. It may be applied over GEO/LEO satellites and HAP platforms. The main difference stands in the round trip time (RTT). The results have been fulfilled by using RTT=100[ms] (HAP environment). The control architecture is centralized: an earth station (or the HAP/satellite itself, if switching on board is allowed) represents the master station, which manages the resources and provides the other stations with a portion of the overall bandwidth (e.g., TDMA slots); each station equally shares the assigned portion between its traffic flows (the fairness hypothesis is made).

Each user requests a TCP/IP service (e.g., Web page or a File transfer) by using the space channel itself (or also by other communication media). The request traffic is supposed negligible. After receiving the request ISPs send traffic through the earth stations and the space link. To carry out the process, each earth station conveys traffic from the directly connected ISPs and accesses the space channel in competition with the other earth stations.

Fading is modelled as bandwidth reduction. From the implementation viewpoint, it means using a FEC code where each earth station may adaptively change the amount of redundancy bits (e.g. the correction power of the code) in dependence on fading so reducing the real bandwidth availability. Mathematically, it means that the bandwidth available for the z-th station is composed of the nominal bandwidth and of the factor , which, in this paper, a variable parameter contained in the interval [0,1].

\[
C_{z}^{\text{real}} = \beta_{z} \cdot C_{z}; \beta_{z} \in [0,1], \beta_{z} \in \mathbb{R}
\] (1)
A specific value $\beta_z$ corresponds to a fixed attenuation level “seen” by the $z$-th station.

The bandwidth allocation defined as a MOP problem may be formalized as:

$$C^{\text{opt}} = \left\{ C_0^{\text{opt}}, ..., C_z^{\text{opt}}, ..., C_{z-1}^{\text{opt}} \right\}$$

$$\arg \min \{ \mathbf{F}(C) \}; \mathbf{F}(C): \mathbf{D} \subset \mathbb{R}^Z \rightarrow \mathbb{R}^Z, \mathbf{C} \geq 0 \quad (2)$$

where: $\mathbf{C} \in \mathbf{D}$, $\mathbf{C} = \left\{ C_0, ..., C_z, ..., C_{z-1} \right\}$ is the vector of the capacities assignable to the earth stations; the element $C_z$, $\forall z \in [0, Z-1]$, $z \in \mathbb{N}$ is referred to the $z$-th station; $C_z^{\text{opt}} \in \mathbf{D}$, is the vector of the optimal allocation; $\mathbf{D}$ represents the domain of the vector of functions. The solution has to respect the constraint:

$$\sum_{z=0}^{Z-1} C_z = C_{\text{tot}} \quad (3)$$

where $C_{\text{tot}}$ is the overall capacity available.

$\mathbf{F} (\mathbf{C})$, dependent on the vector $\mathbf{C}$, is the performance vector

$$\mathbf{F} (\mathbf{C}) = \{ f_0 (C_0), ..., f_z (C_z), ..., f_{Z-1} (C_{Z-1}) \}$$

$$\forall z \in [0, Z-1] \quad (4)$$

The single $z$-th performance function $f_z (C_z)$ (or objective) is a component of the vector and is defined as the average TCP packet loss probability $P_{\text{loss}} (\cdot)$, which is supposed to be a decrescent function of the bandwidth $(C_z)$. It is dependent on the number of active sources $(N_z)$ and on the fading level $\beta_z$, for each station $z$ because it is averaged on the fading level $\beta_z$, which is considered a discrete stochastic variable ranging among $L$ possible values $\beta_z$ happening with probability $p_{\beta_l}$.

$$f_z (C_z) = E_{\beta_z} \left[ P_{\text{loss}} (C_z, N_z, \beta_z) \right] = \sum_{l=0}^{L-1} \left[ P_{\text{loss}} (\beta_l, C_z, N_z) \right] p_{\beta_l} \quad \forall l \in [0, L-1], L \in \mathbb{N} \quad (5)$$

Each “performance function” $f_z (C_z)$ represents a single cost competing with the others to get bandwidth. Operatively, the analytical expression of $P_{\text{loss}} (\cdot)$ is taken from reference [2].

The optimal solution for MOP problems is called POP-Pareto Optimal Point [3], coherently with the classical MOP theory. It was adopted in economic environment and may be summarized as follows.

The bandwidth allocation $\mathbf{C}^{\text{opt}} \in \mathbf{D}$ is a POP if does not exist a generic allocation $\mathbf{C} \in \mathbf{D}$ so that:

$$\mathbf{F} (\mathbf{C}) \leq_P \mathbf{F} (\mathbf{C}^{\text{opt}}), \forall \mathbf{C} \neq \mathbf{C}^{\text{opt}} \quad (6)$$

Concerning the operator “$\leq_P$”: given two generic performance vectors $\mathbf{F}^1, \mathbf{F}^2 \in \mathbb{R}^Z$, $\mathbf{F}^1$ dominates $\mathbf{F}^2$ ($\mathbf{F}^1 \leq_P \mathbf{F}^2$) when:

$$f_{1y} \leq f_{2y} \quad \forall y \in [0, 1,...,Z-1]$$

and

$$f_{1y} < f_{2y} \text{ for at least one element } y \in [0, 1,...,Z-1] \quad (7)$$

Where $f_{1y}, f_{2y}, f_{3y}^z$ and $f_{4y}^z$ are the elements of the vector $\mathbf{F}^1$ and $\mathbf{F}^2$, respectively.

In the considered problem, a POP is a bandwidth allocation where any change to get a lower value of one of the performance functions implies the increment of at least one of the other functions. The constraint in (3) defines the set of POP solutions because, over that constraint, each variation of the allocation, aimed at enhancing the performance of a specific earth station implies the performance deterioration of at least another station due to the decrescent nature of the objective functions.
It is worth noting that, in the proposed methodology, no on-line decision method is applied. The system evolution is ruled by stochastic variables. In practice, \( F(C) \) in the optimization problem (2) is considered to be the average value of the performance vector over all the possible realizations of the stochastic processes of the network. The performance functions are representative of the steady-state behaviour of the system and the allocation is provided with a single infinite-horizon decision.

IV. THE TCP PACKET LOSS PROBABILITY MODEL

The TCP model considered is based on a previous work of the authors [2]. Considering the round trip time (\( RTT \)) fixed and equal for all the sources, taking TCP Reno as reference and considering only the Congestion Avoidance phase of the TCP (supposed always active), the Packet Loss Probability may be analytically expressed as a function of the available bandwidth and of the number of TCP active sources as:

\[
P_{\text{loss}}^z(Z, N_z, \beta_z) = 32N_z^2 \cdot \left[ 3b(m+1)^2 \left( \beta_z \cdot \bar{C}_z \cdot RTT + \bar{Q}_z \right)^2 \right]^{-1}\]

(8)

where:

- \( N_z \) is the number of TCP active sources conveyed in the \( z \)-th earth station;
- \( b \) is the number of TCP packets covered by one acknowledgment;
- \( m \) is the reduction factor of the TCP transmission window during the Congestion Avoidance phase (typically \( m = \frac{1}{2} \));
- \( \bar{C}_z \) is the bandwidth “seen” by the TCP aggregate of the \( z \)-th earth station expressed in packets/s (\( \bar{C}_z = C_z / d \), where \( d \) is the TCP packet size);
- \( \bar{Q}_z \) is the buffer size, expressed in packets, of the \( z \)-th earth station.

The average packet loss probability, used within the allocation methods, is:

\[
E_{\beta_z} \left[ P_{\text{loss}}^z \left( Z, N_z, \beta_z \right) \right] = \frac{32}{3b(m+1)^2} \sum_{l=0}^{Z-1} N_z^2 \cdot \left( \beta_z \cdot \frac{C_z}{d} \cdot RTT + \bar{Q}_z \right)^2 \cdot P_{\beta_z}^z(l)
\]

(9)

\[E_{\beta_z} \left[ P_{\text{loss}}^z \left( \cdot \right) \right] \] is a monotone (decreasing) function, convex \( \forall C_z \geq 0, \forall \beta_z \in [0, Z - 1], z \in \mathbb{N} \).

The model is valid at regime condition of the TCP senders, coherently with the infinite-horizon hypothesis reported in the previous section. Equation (9) has been computed under the hypothesis that all the losses are due to congestion. So, the ideal hypothesis for this paper would be that there is no loss due to channel errors because the FEC code may be extended to a virtually infinite correction power by increasing the correction bits and reducing bandwidth for data. In practice, being the theoretical assumption unfeasible, the implementation carried out in the paper assumes a Bit Error Ratio (BER) below \( 10^{-7} \) by increasing the correcting bits. It implies that the bandwidth available for data is strongly reduced (down to about the 15% of the overall bandwidth, as should be clear from the \( \beta_z \in \mathbb{R} \) values reported in Section VII for performance evaluation), but makes feasible considering almost all the losses (actually all, as supposed in the paper) due to a bandwidth bottleneck (to congestion) and not to channel errors.

V. MINIMUM DISTANCE METHOD (MD) ALGORITHM

The algorithm proposed in this paper, called Minimum Distance (MD), provides a solution of the problem (2), out of the overall set of solutions defined by the constraint (3). It is aimed at approaching the ideal performance, which theoretically happens when each single station has the availability of all the channel bandwidth, by minimizing the Euclidean distance between the performance vector and the ideal solution of the problem. It is a MOP resolution method also identified as GOAL approach [3] and bases its decision on the ideal solution of the problem: the utopia point. In more detail, the ideal performance vector in this case is:

\[
F_{\text{id}} \left( C_{\text{id}} \right) = \left[ f_{0, \text{id}}^{z \text{id}} \left( C_{0, \text{id}} \right), \ldots, f_{Z, \text{id}}^{z \text{id}} \left( C_{Z, \text{id}} \right) \right] \]

(10)

where

\[
f_{z, \text{id}}^{z \text{id}} \left( C_{z, \text{id}} \right) = \min_{\beta_z} E_{\beta_z} \left[ P_{\text{loss}}^z \left( Z, N_z, \beta_z \right) \right], C_z \in [0, C_{\text{tot}}]
\]

(11)

From equation (11), called single objective problem, it is obvious that the optimal solution is given by \( C_z = C_{\text{tot}} \), \( \forall z \in [0, Z - 1] \). So, \( C_{\text{id}} = \left\{ C_{\text{tot}}, C_{\text{tot}}, \ldots, C_{\text{tot}} \right\} \).

Starting from the definition of the ideal performance vector, the problem stated in equation (2) can be solved by the following allocation under the constraint (3):

\[
C_{\text{id}}^{\text{MD}} = \arg \min_{C} \left\{ \left\| F(C) - F_{\text{id}} \left( C_{\text{id}} \right) \right\|_2^2 \right\}
\]

(12)

where \( \left\| \cdot \right\|_2 \) is the Euclidean norm.

MD is though for a fully competitive environment where each station tries approaching its ideal performance. It is not the only possible choice. Some form of cooperation among the stations may be also included, as said in the next section. The comparison among the approaches is reported in the performance evaluation.

VI. BANDWIDTH ALLOCATION METHODOLOGIES FOR COMPARISON

A. General Considerations

The following schemes, already in the literature have been used in section VII for comparison with the MD scheme:

- FIX - where the allocator assigns the same capacity to each station independently of the meteorological and traffic conditions.
• HEU – where the bandwidth allocation is directly proportional to the traffic offered \((N_z)\) and inversely proportional to the fading level \((\beta_z)\).

• ABASC [4] - where the cost minimize is the sum of the packet loss averaged over the fading level.

• NBS [5] - where the cost is the sum of the logarithms base \(e\) of the packet loss of each station averaged over the fading levels (in practice, it minimizes the product of the packet losses averaged over the fading).

The last two methods imply a partial cooperation among the stations to allocate bandwidth, agreed a-priori and formalized through proper cost functions. Such cooperation is not included within MD that models bandwidth allocation as a totally competitive problem. The MD cost function (12) is not representative of any prior agreement among the stations but is aimed at approaching the ideal situation for each. In general, the solution of the allocation problem can be generated with different methodologies. The strategies reported in this paper provide just one solution of the problem (2), out of the overall set of solutions defined by the constraint (3). Even if all the solutions defined by (3) are Pareto optimal, one of them may be preferred depending on a fixed criterion. MOP problems are thought in a fully competitive environment but, for example, if the aim (the criterion) is to get the minimum average packet loss probability over all the earth stations (ABASC), it is necessary to use a method to generate the solution that, within the space defined by the POP set, allows choosing the allocation that satisfy the criterion.

The solutions listed above have different decisional criteria. They are taken from the literature and framed within the MOP environment. It allows not only highlighting their characteristics but also to have an idea of the future possibility offered by the MOP framework.

In more detail:

B. Fixed Allocation (FIX)

The bandwidth allocator assigns the same quantity of capacity to each station independently of the meteorological and traffic conditions. Being \(Z\) the overall number of stations, \(C_z = \frac{C_{tot}}{Z} \forall z \in [0,Z-1], Z \in \mathbb{N}\) (13)

It is obvious to see that the constrain reported in equation (3) is respected and the solution is within the POP set.

C. Heuristic Allocation (HEU)

Being the TCP traffic load offered to an earth station (expressed in number of TCP active connections \(N_z\)) and its fading condition (expressed in terms of \(\beta_z\)) the crucial elements of the bandwidth allocation strategies proposed, a simple heuristic allocation scheme can be defined in terms of them. In more detail, concerning HEU, the bandwidth provided to a station is a weighted portion of the overall bandwidth available for TCP/IP communications.

From the analytical viewpoint, the capacity assigned to the \(z\)-th station is:

\[
C_z = k_z \cdot C_{tot} \quad \forall z \in [0,Z-1], Z \in \mathbb{N}; \quad k_z \in [0,1], k_z \in \mathbb{R}
\] (14)

Where

\[
k_z = \frac{N_z}{\beta_z} \left( \sum_{j=0}^{z-1} \frac{N_j}{\beta_j} \right)^{-1} \quad \text{with} \quad \sum_{z=0}^{Z-1} k_z = 1
\] (15)

The bandwidth assigned to a station increases coherently with the traffic offered to the station and with the rain fading level.

D. Average Bandwidth Allocation for Satellite Channels (ABASC)

The technique takes its origin from a bandwidth allocation scheme originally dedicated to geostationary satellite channels [4]. The cost function used there is the decisional criterion of this methodology in the MOP framework.

The ABASC method generates a solution compatible with the problem because it is a MOP method (it belongs to the “preference function” methods family as defined in reference [3]). In particular:

\[
J_{ABASC}(C) = \sum_{z=0}^{Z-1} E[P_{loss}(C_z,N_z,\beta_z)]; \quad \forall z \in [0,Z-1], Z \in \mathbb{N}
\] (16)

The ABASC strategy distributes the bandwidth by minimizing the sum of the single performance functions. The vector \(C_{ABASC}^{opt}\) of the capacities assigned by ABASC is computed as:

\[
C_{ABASC}^{opt} = \arg \min_C J_{ABASC}(C)
\] (17)

under the constraint (3).

E. Nash Bargain Solution (NBS)

Taking the problem definition directly from [5], it is necessary to define the utility functions: one for each earth station. In this paper the reciprocal value of the TCP packet loss probabilities averaged over the fading levels (the performance functions) have been chosen.

\[
U_z(C_z,N_z,\beta_z) = \frac{1}{E[\beta_z \cdot P_{loss}(C_z,N_z,\beta_z)]}; \quad \forall z \in [0,Z-1], Z \in \mathbb{N}
\] (18)

The utility of each station grows when the average packet loss probability decreases. In practice, \(U_z(\cdot)\) is a crescent function of the capacity assigned to the \(z\)-th earth station. It is also proportional to the average TCP throughput, which is the reciprocal value of the packet loss probability square-root multiplied for a constant [6]. In general, the bargaining problem deals with the maximization of each single utility function by finding a Pareto optimal allocation. The NBS solution solves the bargaining problem and it may be found (as stated in [5]) defining:

\[
J_{NBS}(C) = \prod_{z=0}^{Z-1} U_z(C_z,N_z,\beta_z); \quad \forall z \in [0,Z-1], Z \in \mathbb{N}
\] (19)

and by solving:

\[
C_{NBS}^{opt} = \arg \max_C J_{NBS}(C)
\] (20)
Being each single *utility function* convex, the optimization problem defined in equation (20) may be equivalently expressed by using:

$$J_{\text{NBS}}(C) = \sum_{z=0}^{Z-1} \ln \left[ U_z \left( C_z, N_z, \beta_z \right) \right]$$

$$\forall z \in [0, Z - 1], Z \in \mathbb{N}$$

hence, the solution of the problem (20) may be also found by (22):

$$C_{\text{opt}}^{\text{NBS}} = \arg \max_c J_{\text{NBS}}(C)$$

In conformance to previously described methods, to have also for the NBS strategy, a minimization problem, it is necessary to change the \( \hat{J}_{\text{NBS}} \) sign. Applying the logarithm properties:

$$\hat{J}_{\text{NBS}}(C) = -J_{\text{NBS}}(C) = \sum_{z=0}^{Z-1} \ln \left[ E \left( P_{\text{loss}} \left( C_z, N_z, \beta_z \right) \right) \right]$$

$$\forall z \in [0, Z - 1], Z \in \mathbb{N}$$

In practice, the NBS strategy distributes the bandwidth by minimizing the sum of the logarithms (base \( e \)) of each single *performance function*. The vector \( C_{\text{opt}}^{\text{NBS}} \) of the capacities assigned by the NBS method is computed as:

$$C_{\text{opt}}^{\text{NBS}} = \arg \min_c \hat{J}_{\text{NBS}}(C)$$

under the constraint (3).

### VII. PERFORMANCE EVALUATION

The aim is to evaluate the performance of MD in terms of allocated bandwidth and packet loss probability. The action is fulfilled analytically by varying the fading conditions and the number of TCP active sources.

MD is compared with the schemes previously described: FIX, HEU, ABASC and NBS.

The network scenario considered is composed of 2 earth stations: station 0, always in clear sky condition, and station 1, which varies its fading level according to real fading levels taken from [7] and reported in the first column of Table I. Each station gathers traffic from TCP sources and transmits it to the terminal users through the HAP system. The number of active TCP sources is set to 10 \( , z = \{0,1\} \). The fading level is a deterministic quantity \( (L=1) \) and \( p_{\beta_z} = 1 \forall z, \forall l \) in the tests. The overall bandwidth available \( C_{\text{tot}} \) is set to 4 [Mbps] and the TCP buffer size \( Q_z \) is set to 10 packets (of 1500 bytes) for each earth station. The round trip time is supposed fixed and equal to 100 [ms] for all the stations, it is considered comprehensive of the propagation delay of the HAP channel and of the waiting time spent into the buffers of the earth stations.

#### A. Variable Fading Level

Table I allows identifying the real aim of MD. It shows the Euclidean distance from the utopia point for all the considered schemes by varying the fading level. MD minimizes it and, in a totally competitive environment, where all the stations aim at getting as much bandwidth as possible without any agreed cooperation with the other entities, it provides the optimal allocation.

<table>
<thead>
<tr>
<th>( \beta_1 )</th>
<th>FIX</th>
<th>HEU</th>
<th>ABASC</th>
<th>MD</th>
<th>NBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.156</td>
<td>0.58209</td>
<td>0.61451</td>
<td>0.54506</td>
<td>0.51488</td>
<td>0.9480</td>
</tr>
<tr>
<td>0.325</td>
<td>0.38234</td>
<td>0.37571</td>
<td>0.32444</td>
<td>0.32374</td>
<td>0.6332</td>
</tr>
<tr>
<td>0.625</td>
<td>0.19941</td>
<td>0.18810</td>
<td>0.18786</td>
<td>0.2408</td>
<td>0.51488</td>
</tr>
<tr>
<td>0.833</td>
<td>0.14484</td>
<td>0.12713</td>
<td>0.14234</td>
<td>0.14234</td>
<td>0.1504</td>
</tr>
</tbody>
</table>

The difference with the other schemes is more evident for serious fading conditions \( (\beta_1 \leq 0.625) \), in Table I because, approaching a clear sky condition, all the performance functions (the components of the vector (4)) tend to have the same value. The optimal allocation, in this case, obviously converges towards fairest allocation: the bandwidth is split into two identical parts being the load the same. Similar comment is applicable also for the other schemes.

Figs 3 and 4 show the bandwidth allocated to stations 0 and 1, respectively, versus the fading levels of station 1. FIX method is completely inflexible: it distributes the bandwidth ignoring the channel fading. HEU, ABASC and MD methods follow the behaviour of the channel: they provide more bandwidth to the faded station so penalizing the station in clear sky. HEU penalizes station 0 severely when the fading level is low. ABASC and MD distribute the bandwidth among the stations more fairly. NBS method has a different behaviour: it provides a larger portion of capacity to the clear sky station in case of serious fading for station 1. The motivation of this behaviour is related to the nature of the used cost function. MD, due to the fully competitive view of the problem, tends to privilege the faded station. So its allocation is the closest to the HEU scheme, which considers only the fading level (and the number of TCP connection, fixed here) and does not perform any optimization. In practice, HEU is a solution suited to the fully competitive environment but it does not reach an optimal solution.
The effect on the Packet Loss Probability versus the fading levels is reported in Fig. 5 and Fig. 6, for the Station 0 and 1, respectively. The quantity is shown for all the considered allocation schemes and for the ideal condition where each station uses all the channel bandwidth. MD, chasing the ideal behaviour for each station, optimizes the Euclidean distance with the ideal point and tends to help the faded station.

B. Variable Number of TCP Sources

The second set of tests is aimed at evaluating the performance by varying the number of active TCP sources gathered in the stations. The network scenario is the same considered in subsection A but, in this case, both stations are in clear sky conditions. The difference is only the number of TCP sources activated.

In detail, $N_0 = 10$ is fixed in all tests, while $N_1$ varies as reported in the x-axis of the figures from 7 to 10. Figs 7 and 8 show the bandwidth; Figs 9 and 10 the packet loss probability. Again the FIX method does not provides any flexibility in terms of bandwidth allocated (Figs. 7 and 8). Concerning the packet loss probability, it gives satisfying results only for station 0 (Fig. 9), which is not overloaded, but completely unacceptable for station 1 (Fig. 10). HEU scheme gives some bandwidth to both stations, even if, when the station 1 is overloaded ($N_1 = 40$), it does not provide any benefit concerning the packet loss probability. As in previous subsection, due to the nature of the used cost function, NBS has a different behaviour providing no bandwidth to station 1 because its load is always higher than station 0’s. On the other hand, ABASC and MD (whose macroscopic behaviour is very similar in this case) do not give any bandwidth to station 1 when it is overloaded ($N_1 = 40$) and assign the bandwidth to the other station, obviously improving its performance. The difference between ABASC and MD stands in the distance from the utopia point, whose behaviour, also in the case of variable load, reflects the trend shown in Table I for variable fading levels. The values are not shown here for the sake of brevity.

![Fig. 4. Bandwidth allocated to Station 1 in presence of variable fading.](image)

![Fig. 5. Packet Loss Probability of Station 0 in presence of variable fading.](image)

![Fig. 6. Packet Loss Probability of Station 1 in presence of variable fading.](image)

![Fig. 7. Bandwidth allocated to Station 0 in presence of variable number of TCP sources.](image)
Space systems represent an efficient solution for ubiquitous TCP/IP services. In real deployments, they often work at frequencies where fading due to atmospheric phenomena, in particular rain, has an important role. Bandwidth allocation may represent an efficient rain fading countermeasure. The paper describes bandwidth allocation within the framework of Multi-Objective Programming (MOP) Optimization and introduces a new technique, called Minimum Distance (MD), which exploits the features of MOP environment. The results have shown an optimal performance of MD within a fully competitive view of the nature of the bandwidth allocation problem.

REFERENCES


