A Hybrid Metaheuristic Approach to Optimize the Content Transmission in Multimedia Systems

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Abstract: The advent of the digital television in Brazil has allowed users to access interactive channels. Once interactive channels are available, the users are able to find multimedia content such as movies and breaking news programs, to send and/or receive emails, to access interactive applications and also other contents. In this context, a high demand of requests from users is expected. Therefore, from the content provider's point of view, the determination of transmission parameters is needed in order to ensure the best quality of transmission to every user. The aforementioned identification problem is modelled as an optimization problem and a solution procedure based on metaheuristic techniques is proposed. Genetic Algorithm and Tabu Search metaheuristics are employed separately and coupled in a hybrid scheme to define the best transmission policy, optimizing the transmission parameters, such as audio and video transmission rates. Based on the experimental results, the hybrid algorithm has produced better solutions which meet the quality requirements.

1 INTRODUCTION

Digital TV has promoted technological progress in telecommunications area. Additionally to the quality improvements on audio and video transmission, Brazilian Digital Television System also includes an interactive channel that allows users to access interactive applications, on-demand systems and other resources which are provided by digital content suppliers. The television stations are expected to provide an interactive channel through which clients should access the multimedia content delivery system. In this context, the interactive channel makes possible the communication with the provider multimedia server and data transmission (Manhães *et al.*, 2005).

In order to guarantee a better reception quality for all clients, a proper configuration of transmission parameters must be identified by the content provider. However, it is not a simple task since a variety of families of clients could be identified according their reception features. Therefore, the transmission parameters to be set should maximize the use of the reception structure of every family of clients. Given the set of possibilities related to the reception features, a complex combinatorial problem arises.

Thus, two different metaheuristic models are proposed to optimize content delivery in a multimedia system. They are employed separately and also coupled in a hybrid scheme. The proposed optimization algorithms are compared according to the definition of the best transmission policy. So, the use of a hybrid metaheuristic for optimizing the transmission of multimedia content in Digital TV is one of the contributions of this paper. Furthermore, the development of a mathematical model in accordance with both Brazilian Digital Television System and International transmission rules stated by ITU-T (ITU-T, 2000) should be emphasized.

This paper is organized as follows. Section 2 presents the proposed architecture. In Section 2.1, the mathematical model is defined. In Section 2.2, the proposed metaheuristic models are presented. The experiments and results are discussed in Section 3. Finally, conclusions are presented in Section 4.

2 PROPOSED ARCHITECTURE

A prominent feature in the Brazilian Digital Television System is the interactive channel. The

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interactive channel is an additional resource that enables users, individually and independent from the others, to interact with broadcasters by sending or receiving information and requests. To allow the information exchange between de users and the TV station a connection is needed, usually through an internet network. The transmission dynamics is depicted in Figure 1.

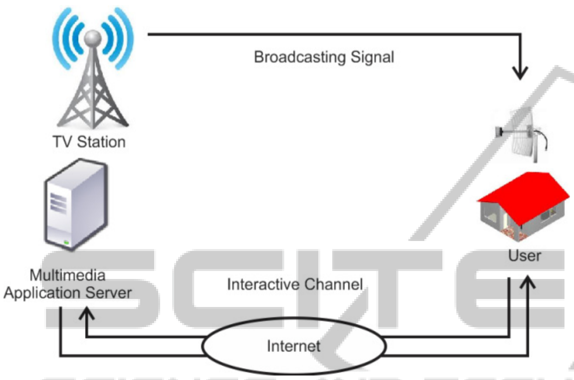

Figure 1: The transmission dynamics.

Based on this premise, the user authentication is requested to connect to a multimedia content delivery system. After the authentication, a communication between the user and the content provider is established. From this moment, users can request specific programs, multimedia contents or TV products to be broadcasted by the TV station. All the communication between television station and the user is performed through an additional communication channel rather than the broadcasting channel. In the Brazilian Digital Television System this communication channel is named interactivity channel, depicted in Figure 2.

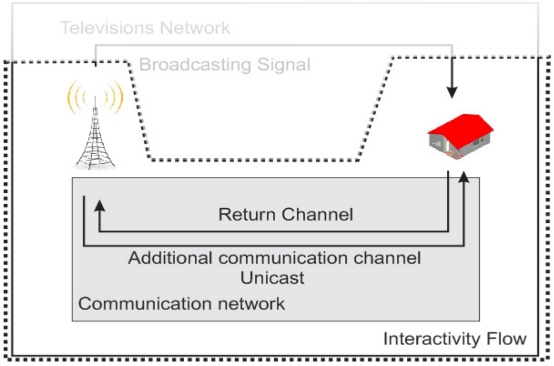

Figure 2: Interactive channel.

After the connection is established, the server calls from time to time an optimizer agent to determine the best way to deliver the content to the end user. In this context, the optimizer agent runs a metaheuristic scheme to identify the set of transmission parameters to guarantee the best use of the bandwidth with maximum reception quality, according to the device network capacity.

In Figure 3, the proposed system dynamics is depicted.

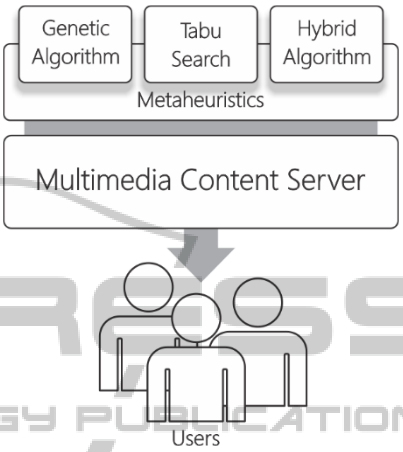

Figure 3: The proposed system dynamics.

After the user connection is established, the control is passed to the transmission content module. The coordinator and optimizer agents are included in this module. The coordinator agent controls the other agents to run the metaheuristic with the objective to determine the parameters for the best content transmission policy. At the end of this process, each optimizer agent transmits the results found by the metaheuristics to the coordinator agent. Following, an analysis is performed by the coordinator agent to identify the best configuration that was chosen according to the transmission content related do the user. The content streaming could be transmitted over any network model, for instance: IPTV (Internet Protocol Television), broadcasting or multicasting. After the transmission is finished, the communication channel is closed.

2.1 Mathematical Formulation

This section presents the mathematical model for the problem of optimal identification of transmission parameters. The referred optimization problem could be formulated as a multi-objective problem since a compromise solution, based on the transmission parameters, should be identified in order to ensure video and audio quality for all the families of clients. Nevertheless, in this work, the combinatorial optimization was modelled as a single-objective optimization problem by aggregating the objectives in a weighted sum.

The objective function (OF) is defined based on decision variables which represent five different video qualities and two different audio qualities. The constraints define the domain values of the decision variables and assume a upper value for the bandwidth. This mathematical formulation is used in the optimization procedure to find the best possible utilization of the server bandwidth in order to attend all connected clients. This problem resembles a classical combinatorial optimization problem, the Selection Parts Problem. The problem of selecting parts belongs to the class of NP-Complete complexity problems (Kusiak *et al.*, 1984).

$$\begin{aligned} MAX\ OF = {} & \alpha\left(\sum_{n=1}^{nLD} vLD_n\right) + \\ & +\beta\left(\sum_{n=1}^{nSD} vSD_n\right) + \gamma\left(\sum_{n=1}^{nHD} vHD_n\right) + \\ & +\delta\left(\sum_{n=1}^{nP1} vP1_n\right) + \omega\left(\sum_{n=1}^{nP2} vP2_n\right) + \\ & +\theta\left(\sum_{n=1}^{nST} aST_n\right) + \rho\left(\sum_{n=1}^{n51} a51_n\right); \end{aligned} \tag{1}$$

subject to:

$$0.01 \le vLD \le 1.00; \tag{2}$$

$$1.00 \le vP1 \le 2.00; \tag{3}$$

$$2.00 \le vSD \le 5.00; \tag{4}$$

$$5.00 \le vP2 \le 10.00; \tag{5}$$

$$10.00 \le vHD \le 18.00; \tag{6}$$

$$0.096 \le aST \le 0.256; \tag{7}$$

$$0.384 \le a51 \le 1.00; \tag{8}$$

$$SB = 500; \tag{9}$$

$$\alpha, \delta, \beta, \omega, \gamma, \theta, p > 0; \tag{10}$$

$$nLD, nSD, nHD, nP1, nP2, nST, n51 \in \mathbb{Z}^{+}; \tag{11}$$

$$\begin{aligned} & \left(\sum_{n=1}^{nLD} vLD_n\right) + \left(\sum_{n=1}^{nSD} vSD_n\right) + \\ & + \left(\sum_{n=1}^{nHD} vHD_n\right) + \left(\sum_{n=1}^{nP1} vP1_n\right) + \\ & + \left(\sum_{n=1}^{nP2} vP2_n\right) + \left(\sum_{n=1}^{nST} aST_n\right) + \\ & + \left(\sum_{n=1}^{n51} a51_n\right) \le SB, \end{aligned} \tag{12}$$

where:

- *SB* = total bandwidth of the television station server (total flow system);
- *vLD* = LD (Low Definition) video quality;
- *vSD* = SD (Standard Definition) video quality;
- *vHD* = HD (High Definition) video quality;
- *vP1* = intermediate configuration between LD and SD;
- *vP2* = intermediate configuration between SD and HD;
- *aST* = stereo audio quality;
- *a51* = multichannel 5.1 audio quality;
- *nLD* = number of clients connected as LD;
- *nSD* = number of clients connected as SD;
- *nHD* = number of clients connected as HD;
- *nP1* = number of clients connected as P1;
- *nP2* = number of clients connected as P2;
- *nST* = number of clients connected as stereo audio quality;
- *n51* = number of clients connected as multichannel 5.1 audio quality;
- *α* = importance level of the LD transmission;
- *β* = importance level of the SD transmission;
- *γ* = importance level of the HD transmission;
- *δ* = importance level of the P1 transmission;
- *ω* = importance level of the P2 transmission;
- *θ* = importance level of the Stereo Audio transmission;
- *ρ* = importance level of the multichannel 5.1 transmission;
- All decision variables are assumed as real numbers.

The mathematical formulation shows that the system bottleneck is the bandwidth available in the multimedia content delivery system. This is a limited resource and has a high cost. Therefore, the optimization procedure must provide a parameter configuration which is able to utilize this resource in the best possible way. The constraints are defined in equations (2) to (12).

The equations (2) to (8) define the domain values of the Video Quality (VQ) and Audio Quality (AQ) in accordance with international standards defined by ITU-T (ITU-T, 2000). These ranges are defined according to the quality of video transmission (SD, LD, HD, P1 and P2). The equation (9) limits the bandwidth available in the multimedia server of the TV station.

Equation (10) defines the parameters $\alpha, \beta, \gamma, \delta, \omega, \theta$ and ρ which must be greater than zero. These parameters are used to set a priority for a particular type of transmission, when congestion on the server is verified, with a large number of clients connected. In this case, a specific video quality can be prioritized, for example, the SD transmission, which consumes a lower bandwidth than HD.

Equation (11) defines how many clients the multimedia server is able to serve with a reasonable quality.

Equation (12) defines that the sum of Video Quality (LD, SD, HD, P1 and P2) and Audio Quality (stereo and multichannel 5.1) should not exceed the bandwidth available on the server.

2.2 Metaheuristics

The use of metaheuristics to solve the parameter optimization problem in the context of IPTV content transmission was addressed in (Weissheimer Jr., 2011), where a model based on the application of metaheuristics is presented to find the best transmission parameters configuration on an IPTV platform, assuming different types of receiving devices and users.

A system to configure parameters of digital TV video encoder using the H.264 standard has been proposed in (Linck, 2011). The referred work is based on Tabu Search and Genetic Algorithm metaheuristics. A hybrid algorithm based on these metaheuristics was developed. The Tabu Search metaheuristic was used to intensify the search in conjunction with the power of diversification of Genetic Algorithms. This hybrid approach was applied in the solution of combinatorial optimization problems related to the encoding and decoding video signals.

A new approach to perform the optimization of bandwidth usage to ensure Quality of Service (QoS) for IPTV broadcasts was developed in (Kandavanam *et al.*, 2009). A new algorithm combines Genetic Algorithm and Variable Neighborhood Search metaheuristics to solve the optimization problem. Good results were achieved, since there were significant improvements in the distribution of the available internet link, the maximum use of available internet link and also in the rejection rate of service. In the present work, Genetic Algorithm and Tabu Search were applied together resulting in a hybrid algorithm. These techniques are the same used in (Linck, 2011) and (Weissheimer Jr., 2011), however in a different problem. Following, the proposed optimization metaheuristics are presented

2.2.1 Genetic Algorithm

The Genetic Algorithm (GA) was proposed by John Holland (Holland, 1975). It has been applied to solve combinatorial optimization problems in different areas such as mathematics, physics, biology, engineering, industrial automation, among others. According to Goldberg (1989), GAs are search algorithms based on mechanisms of natural selection and natural genetics. They employ the survival-of-the-fittest principle and propose a random exchange of information.

The initial population of the Genetic Algorithm (GA) is randomly generated and should adequately map the search space. The selection process used in this work is based on the tournament method. The population is sorted in descending order according fitness, and a random number is drawn from a uniform distribution in the interval [0, 1]. If it is less or equal than 0.75, two individuals are chosen randomly from the superior half of the population, i.e. from the best individual portion. On the other hand, if the random number is higher than 0.75 one individual from the superior half is selected and the other one is selected from the inferior half of population (Filho and Tiberti, 2006). By using this method, a worst fitted individual has the chance to be crossed with better fitted individuals. This strategy can lead the algorithm to unexplored areas and thus improve the objective function value over the generations.

The arithmetic crossover operator is responsible for crossing the genetic information of parent individuals to generate new individuals. It is used with a predefined probability. The uniform mutation is the genetic operator used to guarantee the search space exploration and also maintain the diversity of the population. It is also used with a predefined probability.

The stopping criterion adopted in this work was the maximum number of generations which was set to 100.

2.2.2 Tabu Search

Tabu Search (TS) is a metaheuristic proposed by Fred Glover (1986). It consists of a set of concepts and practices used to solve combinatorial optimization problems. This technique is used to find approximate solutions to complex problems, where the time to find the optimal solution is exponential or factorial.

The search process is based on the generation of neighborhood solutions, also called Local Search (LS). The two basic elements of TS are the search space and neighborhood structure. However, the main difference between the TS and the LS is a list that restricts the algorithm in order to prevent reverse movements, called Tabu List, hence the name Tabu Search. Through this mechanism, the algorithm has the ability to escape from local optima, spanning a wider search space and producing better results (Gendreau *et al.*, 2001). The size of the tabu list is defined according to the experiment. The aspiration criteria is used to ensure the OF improvement if a movement is tabu.

Different neighborhood structures based on different types of movements have been proposed to generate new solutions in the Tabu Search (Glover and Laguna, 1997), including swap, insertion and removal. In this work a random removal/insertion movement was used.

The stopping criterion adopted in this work was the number of interactions without OF improvement. This parameter is named Nmax and was set to 100 (Chung *et al.*, 2011).

2.2.3 The Hybrid Algorithm

The proposed Hybrid Algorithm uses the concepts of the GA and TS metaheuristics. It combines the exploration capacity of GA together with the exploitation power of TS.

In the Hybrid Algorithm the TS is initially performed until the stopping criterion is satisfied, i.e., until the number of iterations without improvement in OF value reaches 100. The 20 best solutions obtained in TS phase are used as the initial population of the GA. Following, the GA is performed until the maximum of 100 generations is reached. After the end of a complete cycle (TS+GA), the best solution obtained in GA is returned to TS, from which a new hybrid optimization cycle starts. In the hybrid algorithm, together with the objective function defined in equation (1) an additional criterion was used to evaluate the solution quality. This criterion is represented by the Harmonic Mean (HM) which is also computed at the end of TS and GA phases. The HM is a secondary criteria used to identify the best solution when two different solutions present the same OF value. The HM is computed as follow in equation (13):

$$HM = \frac{n}{\frac{1}{x_1} + \frac{1}{x_2} + \cdots + \frac{1}{x_n}} = \frac{n}{\sum_{i=1}^{n} 1/x_i}, \qquad (13)$$

where n is the total number of clients families, $x_i > 0$ is the transmission rate value assigned for the i-th client. So, the hybrid algorithm has used as stopping criterion the number of 20 complete cycles (TS+GA) without improvement on both the Objective Function (OF) and the Harmonic Mean (HM).

3 EXPERIMENTS AND RESULTS

The experiments to validate the proposed algorithm were made through the harmonic mean of the results generated by the Genetic Algorithm, Tabu Search and Hybrid Algorithm.

3.1 Tuning of Parameters

To avoid biased solutions, the OF weights were tuned by normalization. Based on 100 runs of hybrid algorithm with a random initial solution assumed, the average value of each decision variable is obtained. The corresponding weights (α, β, γ, δ, ω, θ and ρ) were computed by the quotient of the sum of the average values and each average value. This procedure allows to identify the contribution of each decisions variable on the OF value. The respective weight values are presented in Table 1.

Table 1: Definition of Objective Function Weights.

Variable	Average	Parameter	Weight
vLD	0.392	α	58.079
vP1	1.219	β	18.689
vSD	2.694	γ	8.452
vP2	6.033	δ	3.775
vHD	11.349	ω	2.007
aST	0.539	θ	42.266
a51	0.548	ρ	41.594
Total	22.773		

Beyond the weights used in the objective function, the parameters used in AG and TS metaheuristics should be tuned as well. For AG metaheuristic, different combinations of both crossover and mutation probabilities were evaluated for the solution of a small scale instance. From a set of 100 runs performed for each possible combination, the experiments showed the crossover probability equal to 75% and the mutation probability equal to 15% as the best tuning. Parameters of TS metaheuristic should also be set by performing tuning experiments. Different values of both neighborhood size and the tabu list size were evaluated. The best values for the parameters to be tuned were identified by performing a set of 100 runs when solving a small scale instance. The tuning experiments indicated a neighborhood size equal to 100 and a tabu list size equal to 25 for small instance and 250 for medium and large instances.

3.2 Optimization Algorithm for Quality of Transmission

The optimization algorithm aims to optimize the quality of transmission of generic content that is transmitted taking into account the number of connected clients in a multimedia server.

Firstly, a validation experiment comparing the performance between a linear relaxed optimization algorithm and the Genetic Algorithm and Tabu Search metaheuristics was carried out. Next, the experiments were performed taking three different test programs: (*i*) a small scale instance with 15 clients; (*ii*) a medium scale instance with 1,000 clients and (*iii*) a large scale instance with 15,000 clients.

Initially, a comparison experiment was carried out assuming two different solution strategies. The 15 clients instance was solved using exact and metaheuristic approaches. The Simplex Method, through the use of LINGO software, had its performance compared with GA and TS metaheuristics.

In this experiment, the constraints were relaxed and the decision variables (*vLD*, *vP1*, *vSD*, *vP2* and *vHD*) were limited in a range of 0.01 Mbit/s to 100 Mbit/s. Figures 4-6 show the results obtained by using Lingo and the metaheuristics.

It should be noted that Lingo obtained the best values, but it has prioritized only five clients. The respective five clients can be identified in Figure 4 by the transmission values between 79 and 100 Mbit/s. On the other hand, Figures 5 and 6 show that the metaheuristics, which employ the HM metric, has not achieved best OF values, but it makes

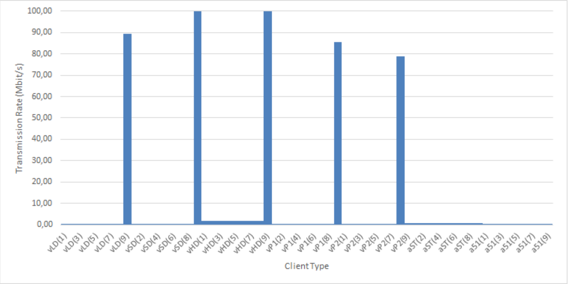

Figure 4: Bandwidth distribution achieved by Lingo.

possible the inclusion of almost all clients in the transmission.

Figure 5: Bandwidth distribution achieved by GA.

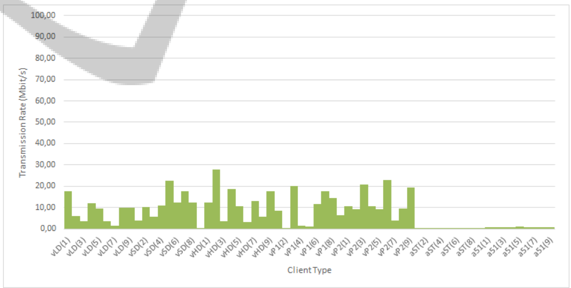

Figure 6: Bandwidth distribution achieved by TS.

In order to understand the behavior of the objective function and the harmonic mean a comparative graphic is shown in Figure 7.

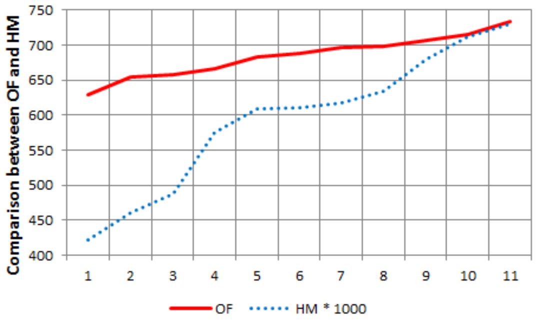

Figure 7: Comparison between OF and HM.

Figure 7 presents the evolution of both the OF and the HM values as the number of iterations increases. It is possible to observe an improvement of both the OF and HM values compared to the initial solution. The initial value of the OF was 629.992 Mbit/s while the final value was 733.116 Mbit/s. It represents an improvement of approximately 16% over the initial value. Considering the HM metric, the initial value was 0.422 MBit/s and the final value was 0.730 Mbit/s. It represents an improvement of approximately 73% over the initial value

3.2.1 Small Scale Experiments

Figure 8 shows a comparison of the final results obtained by GA, TS and HA based on the harmonic mean metric for the small scale instance. These results are average values computed from 100 runs of each optimization scheme. In this experiment, it was assumed that each video quality (LD, P1, SD, HD and P2) is requested by three clients, totalling 15 clients. Concerning audio quality, it was assumed that stereo audio is requested by five clients and 5.1 multichannel audio is requested by ten clients. The Server Bandwidth (SB) was limited in 70 Mbit/s.

As it can be observed from Figure 8, GA and TS have achieved similar results and the HA had the best performance with a harmonic mean of transmission rate equal to 0.73 Mbit/s with a corresponding OF value of 733.116 Mbit/s. Moreover, Fig. 6 also presents standard deviations values (SDev) computed based on results of each metaheuristic. Once more, HA has achieved best results with smaller SDev values

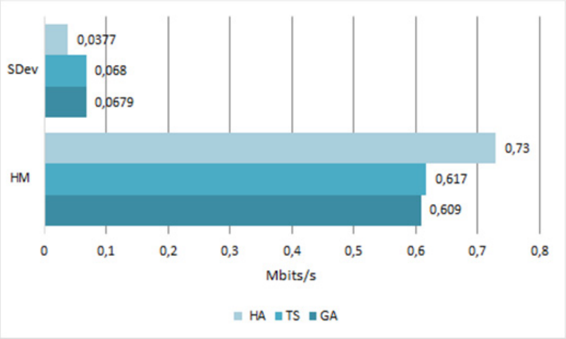

Figure 8: Harmonic mean and standard deviation (small scale problem - 15 clients).

3.2.2 Medium Scale Experiments

Figure 9 shows the respective results for an experiment performed considering a medium scale problem. Once more, these results are average values computed from 100 runs of each optimization scheme. In this experiment, it was assumed that each video quality is requested by 200 clients, totalling 1,000 clients. Concerning audio quality, it was assumed that stereo audio and 5.1 multichannel audio were requested by 500 clients each. The server bandwidth was limited in 700 Mbit/s. Once again, the best result was achieved by HA metaheuristic, with OF value equal to 7,917.530 Mbit/s and harmonic mean of 0.374 Mbit/s. Also, the smaller standard deviations value was achieved by HA metaheuristic.

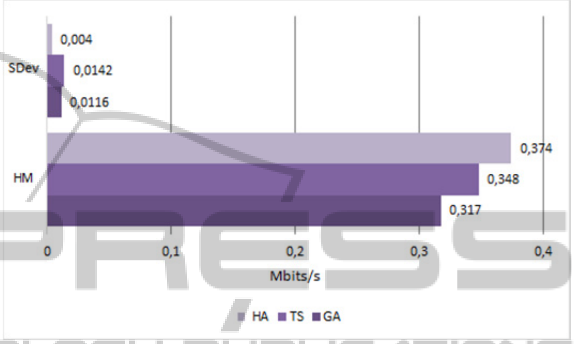

Figure 9: Harmonic mean and standard deviation (medium scale problem - 1,000 clients).

3.2.3 Large Scale Experiments

Lastly, Figure 10 shows a comparison of the final results obtained for a 15,000 clients instance. Concerning video quality, the clients were grouped in the same five groups as presented in last two experiments, with 3,000 clients each group. Regarding the audio quality, the total of 15,000 requests was equally divided, with 7,500 clients requiring stereo audio quality and others 7,500 clients requiring 5.1 multichannel audio. The server bandwidth was limited in 7,000 Mbit/s. Again, the HA metaheuristic has achieved the best harmonic mean results. Moreover, the standard deviation values have shown once more the HA robustness and effectiveness.

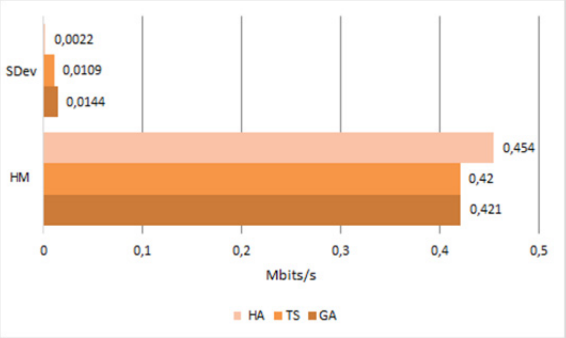

Figure 10: Harmonic mean and standard deviation (large scale problem - 15,000 clients).

4 CONCLUSIONS

This paper presented a model for the content delivery optimization, based on the bandwidth requirements on the multimedia content delivery system. Based on the implementation and the experiments, it was observed that the proposed optimization model provided solutions which met the specified requirements. Comparing the results obtained by the metaheuristics, the hybrid algorithm achieved the best results.

The main contribution of this work is the proposal of a hybrid algorithm that generates good quality solutions, optimizing content delivery in a multimedia system. These solutions are applicable in the Brazilian Digital Television System.

As future work, a more complex algorithm must be developed, which contemplate specific data traffic, features and behaviours. Also, a multi-objective optimization model should be developed in order to evaluate the proposed hybrid metaheuristic robustness. Besides, additional experiments must be performed with the proposed metaheuristics using other mutation and crossover operators, for a better intensification and with the aim of improving the results in specific scenarios and environments.

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