Hybrid Multicriteria Model for Return Channel Selection in IDTV Environment

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***Abstract* – The purpose of this paper is present a hybrid multicriteria model which combine multivariable linear regression, to define weights for criteria to decision making, with multicriteria decision making model – TOPSIS and ELECTRE III. This combination is to be used to select return channel from iDTV Environment. This proposal extracts weight vector from knowledge the collected data from real scenarios, without the need of specialists, as usually is the case with traditional methods. This resulted in a generic and flexible model and has been validated with a case study that ordered the preferred technologies that have been evaluated: ADSL2+, 3G, WiMAX and PLC.**

***Keywords*— Intelligent Systems, Interactive Digital TV, Multivariable Regression, Model Decision Making, Service Provider and Return Channel.**

I. Introduction

Interactive Digital TV environment allows a new class of services around broadcast of television content, in this aspect, service providers have to plan the implantation of technology, based on new demands that will be part of computing environments. The diversity of broadcast applications and usage of an Interactive Channel, as external communication in the Brazilian context, leads to a case-study with the objective to consider the social inclusion specified in Brazilian Presidential Decree No. 4901.

It's even more necessary as the Brazilian Digital TV System (SBTVD) presents as a promising alternative when considering digital inclusion, since the television is present in more than 90% of Brazilian homes, according to National Survey by Household Sample of Brazilian Institute of Geography and Statistics (IBGE) [1]. It is also available to virtually all social classes, in all regions of Brazil, which is not true in the case of other communication devices, such as computers.

Therefore, one can consider that Digital TV has a great scope and it should not be restricted to a mere process of improving the quality of transmission. It must be considered as a tool for digital inclusion, naturally with strong possibility of interactivity.

In this context, a universe of activities involving production of audio/visual content to include applications that allow the user to interact with the interactive TV applications has been growing. The possibility to offer applications to viewers by means of Interactive Digital Television originates a new production chain involving programs and applications development of interactive character. Based on this aspect, service providers should be concerned with the diversity of applications and services that can be offered.

One of the main challenges, for social and digital inclusion through Digital TV, is to enable the population, mainly located in areas of difficult access and low-income, to gain access to services such as t-health, t-education, as well as to interactivity (e.g. online shopping, chats, video conferencing services). To this end, allowing such facilities to be available in homes with access to traditional broadcast TV characterizes a major challenge to access providers.

This challenge is closely related to the capacity/availability of access networks, whose capillarity must be much larger with respect to what is now available for Internet services.

Thus, it is fundamental to address the issue of first mile, i.e., the first technology with which a user connects to a telecommunications network; this term is used synonymously with technology access that ensures the interactivity (return channel) service. Studies must be conducted so that service providers have an idea of system performance characteristics. In order to achieve this, scenarios must be studied and understood so that applications embedded in SBTVD are available to the end user, so that providers can anticipate problems in the system.

Studies must consider combining features of access networks (return channel), quality of service (QoS) requirements associated with applications, degree of interactivity such applications impose on the system and possible strategies for planning the capacity of interactive services.

As a contribution, this article proposes a provision of service strategies for selecting return channel within interactive digital TV (iDTV) environment. This approach is based on a combination of multivariable regression with TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and ELECTRE III (Elimination and Choice Translating Reality), enabling decision making from a set of QoS parameters. With respect to measures, test results are obtained for measuring the delay, throughput, jitter, response time, data dropped and number of retransmissions from access technologies.

It is important to note that the proposed approach is generic and flexible and can easily incorporate other parameters and technologies, providing new decision making for different scenarios.

The article is organized as follows: the second section shows published literature and the real contributions of this article; the third presents models for decision making, showing the methods adopted in this article; in the fourth section tests, scenarios, characterization of load and simulation are addressed; the fifth section shows the application of multivariable linear regression, and the extraction of the weights of the application; the sixth section contains tests to evaluate the first miles; the seventh section presents the heuristic used for multicriteria decision making and analyzes the results of experiments, making the comparison between TOPSIS and ELECTRE III; the last section has the conclusions of the authors.

II. RELATED WORK

With a constantly changing environment, several studies, published in the areas of service provider, Digital TV, access technologies and methods for decision making, show that strategies for providing service to select the return channel is an emerging field of research.

Digital TV systems can be represented using a layered architecture where each layer provides services for the upper layer and uses services from the lower layer. The representation of the architecture is the same for all systems and the differences are shown in different parts of the architecture related to the process of modulation, coding, compression, transmission, running applications and adopted middleware. The latter, in the Brazilian case, is called Ginga.

Several studies address the issue of how to connect the end-user to the telecommunications networks, as reviewed by [2]. Authors in [3] address the concern in the behavior of networks given the increase in the number of end users with access to systems like ADSL (Asymmetric Digital Subscriber Line), cable modem, wireless, PLC (Power Line Communication) and optical fiber.

In [4] The results provided evidence to determine the suitability of WiMAX (Worldwide Interoperability for Microwave Access) as a return channel for most interactive applications of digital TV; In [5] are used a generic architecture that combines PLC as a return channel for interactive digital television.

There is also research that considers using 3G access technology for digital TV. In [6] is investigated end-to-end performance adopting 3G as return channel. The motivation was to understand the behavior of radio technology as return channel for an interactive Digital TV.

Among the range of access technologies available in the market, the selection of access technology to be used by the service provider is the subject much discussed in the literature. As in [7], that uses the stochastic control technique, Markov Decision Process (MDP), studies and examines the relationship between optimal decisions that should be applied by the service provider.

Another aspect found in the literature is related to the increase in the number of interactive digital television devices, which, in turn, will generate an increase in accessing telecommunication infrastructures, and thus leading to congestion problems. In [8] and [9], the authors propose a method for adaptive congestion control for the intensive telecommunication traffic expected in case of integrated communication to broadcasting services. A method was proposed, based on sample monitoring, to allow access control, for volatile traffic in interactive television services.

One way to measure the load of the systems being used in order to prevent bottlenecks is by using monitoring and control tools. For this, it is important to comment on the concept of multicriteria decision making methods.

The use of heuristics for multicriteria decision making has been widely used, as shown in [10], with several papers addressing algorithms for selecting the return channel in heterogeneous environments, such as [11], [12], [13], [14], [15] e [16], with different kinds of models.

In order to create a heuristic for the proposed decision making, a technique is investigated to extract knowledge from the collected data from real scenarios. Linear regression estimates conditional value (expected value) of a variable y, given values to other variables x. Multivariable Linear Regression extends simple linear regression onside ring multiple input or explanatory variables. According to [17] MLR may be established through explanatory variables X, with m columns and n lines. With a column vector consisting of resulting variable y, 1 column and n lines, it is expected to establish a linear relationship X and y. So, regression deals with estimating a expected conditional value.

Decision making is used to select a best option from pre-established criteria. Analytical methods consider criteria, with support from decision maker and aids in decision making process. Criteria characterize the system and each criterion has an associated weight that informs the importance of that criterion. All the associated weights form an array of weights.

A domain specialist, usually, assigns the array of weights, by analyzing the established criteria and evaluating the degree of their importance. The academic community accepts this sort of definition. However, different results are obtained based on different specialists' opinions and results differ very much even the criteria are the same [18].

So, the objective of the work presented in this paper is to employ MLR to define array of weights in decision making. TOPSIS and ELECTRE III analytical methods of multicriteria decision making were used. The combined use of linear regression with multicriteria methods for decision making is quite new. So, very few publications report this topic and those avaliable leave several gaps[1] that must be observed.

In [19], the authors propose a regression approach for estimating the decision weights of AHP using linear mixed models (LMM). Other than determining the weight vectors, this model also allows us to decompose the variation or uncertainty in experts' judgment. In particular, the variation among experts and the residual uncertainty due to rounding errors in AHP scale or due to inconsistency within individual expert's judgments can be estimated and rigorously tested using well-known statistical theories.

[1] The term gap refers to a certain research has ceased to be considered in a paper.

The combined use of linear regression with multicriteria methods for decision making is new, and the existing studies don't include some gaps that need attention, to ensure the proposed heuristic, which include: the lack of studies using heuristics, based on multicriteria analysis, using data collected in real scenarios; testing implementations on real devices; implementation of heuristics in open platforms; using Multivariate Linear Regression to define the weight vector; using the TOPSIS and ELECTRE III methods from a weight vector based on simulation tests, not experts opinion; comparison of different technologies that are already consolidated in the market.

III. TESTS

Once the models that would be used were selected, a typical scenario was set for transmission of digital content, and a server was configured to respond to the user requests, simulating an iDTV service infrastructure. Thus, characterization of the load of a typical digital TV was obtained. Figure 1 shows the infrastructure, with a transmission layer, responsible for transmitting the television programs for broadcast and interactive applications.

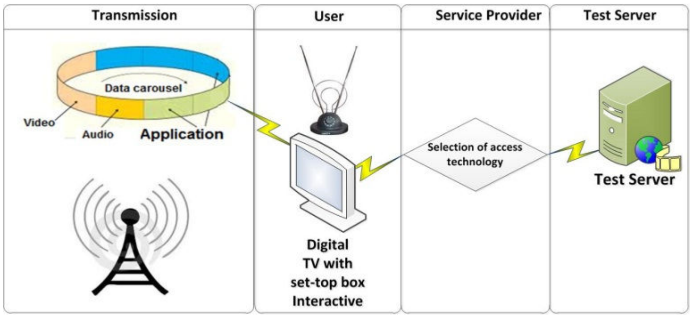

Fig. 1. Scenario tests the application of Digital TV

The application is received and executed in the user layer, which has a TV with a connected set-top box and access technology for a return channel. The infrastructure of the return channel is represented in the service provider layer and can be wired or wireless, leaving it to the provider to decide which technology is to be employed.

The layer of the test server is responsible for responding to requests from tests, with only the application server, which has the function of helping in the measurement criteria used for decision making.

The aforementioned scenario was set to extract measurements of a typical network of Digital TV. The application used in these tests was developed by the research group of this article, and is called DTV-Educ 2.0 [20].

The purpose of this application, a chat conversation, is to make it available for regular television program, so that a student who is watching television can make classroom questions in real time or even conduct group work with other students.

A. Characterization of load application

To characterize the load application in the network, tests were performed where two real users, for 10 minutes, exchanged messages via chat provided by the application.

All application information was recorded during the conversation via a spy program network, and Table I summarizes the measured statistical results of this application.

TABLE I. VALUES DTV-EDUC 2.0

Parameter	Value
Packets Transmitted	575
Average Packet per Second	1.016
Average Size of Package	59.927 bytes
Average Throughput	60.898 bytes/s

The measured data in Table I were used for configuring the application in a simulation scenario. It is noteworthy that this application when compared with other types of traditional applications doesn't occupy the network very much, because its traffic is only in plain text that is typed by users. In general, applications used in digital TV environment present this behavior.

From the characterization of the DTV load application other parameters that would be inserted in the simulation environment were set.

B. Definition of applications and parameters

After characterization of load application, it was necessary to conduct a research on commonly used flow on the Internet. The idea is to make the environment of a user utilizing an interactive application as close to a real scenario as possible.

So, three streams that were used in simulation tests were defined: (i) application of video (video conferencing), (ii) application of voice over IP (VoIP), (iii) typical application of digital TV (DTV-Educ 2.0). These three applications aimed to model traffic used by typical customers who use the Internet, and the first two were taken from [21].

The probabilities of some configuration parameters within Digital TV application were obtained (from empirical studies) to characterize the traffic load and they were fed as input to the simulator. The specification of the traffic load for the application DTV-Educ 2.0 is found in Table II.

TABLE II. PARAMETERS FOR DIGITAL TV APPLICATION

Configuration parameter	Value
HTTP Especification	HTTP 1.1
Page Interarrival Time (seconds)	Weibull (0.30419, 0.1139)
Page Properties	Lognormal (4.2996, 0.25489)
Type of Service	Best Effort (0)

The configurable parameters for video traffic and VoIP application are presented in Table III and IV, respectively.

TABLE III. PARAMETERS FOR VIDEO APPLICATION

Configuration parameter	Value
Frame Interarrival Time (sec)	Constant (0.1)
Frame Size (bytes)	Exponential(15625)
Type of Service	Best Effort (0)

TABLE IV. PARAMETERS FOR VOICE APPLICATION

Configuration parameter	Value
Silence Length (sec)	Exponential(0.65)
Talk Spurt Length (sec)	Exponential(0.352)
Encoder Scheme	GSM (silence)
Voice Frames per Packet	1
Type of Service	Best effort (0)

Thus, applications have been developed and their characteristics were modeled using the parameters configurable by the simulator.

C. Simulation of a scenario

The development of the simulation tests required a tool that can simulate the performance of the network. Thus, OPNET Modeler was opted, which is widely used as a tool for modeling telecommunications networks, and their work environment allows creating a network from a library of templates, and setting parameters not only for the environment, as well as for each object that is composed, and the impacts of its variations [22].

Through this software, it was possible to observe the behavior of a network based on WiMAX, with the parameters defined in the previous section.

Settings were made with parameters of real devices in order to make the simulation as realistic as possible, by applying these settings in the simulator.

After analyzing the data input and configuration of the simulator, simulations were performed using a simulation time of 15 minutes to set up each scenario. This time was defined from literature of area.

The tests were done thoroughly from the variation in the number of users on the network (until 40 users) and the change of seed of the simulation, which meant that for the same amount of users, different values were obtained. An extensive database was generated and consolidated, containing all the measured results of simulation experiments.

D. Applying Multivariable Linear Regression

After the organization of the database, a multivariable linear regression was used to assess the influence (weight) that each parameter has on the final result (selection of return channel).

The general formula of multiple regression models can be specified as:

$$Y_i = A_0 + A_1 X_{1i} + A_2 X_{2i} + \cdots + A_k X_{ki} + u_i$$

A general multiple regression system may be represented as matrix form:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & X_{12} & \cdots & X_{1k} \\ 1 & X_{21} & X_{21} & \cdots & X_{21} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & X_{n1} & X_{n2} & \cdots & X_{nk} \end{bmatrix} \times \begin{bmatrix} A_0 \\ A_1 \\ \vdots \\ A_k \end{bmatrix} + \begin{bmatrix} u_0 \\ u_1 \\ \vdots \\ u_k \end{bmatrix}$$

Where: *Y* is column matrix of size *n x 1* of observations or records of dependent variable or target variable Y*;* *X* is a matrix of size *n x k*, i.e., *n* observations e *k* variables, in which the first column represents intercept A_0; *A* is a column matrix of *k x 1* unknown parameters; *u* is a column matrix with perturbations.

This specification (above equation) generates values to *A* by employing Ordinary Least Squares - OLS. OLS estimates parameters to *A* with least variance without bias and minimizes the sum of squared errors of the estimated regression.

The result of applying OLS to the presented model is given by: $A = \left(X^t X\right)^{-1} \times X^t Y$

In order to verify the application of regression, i.e., ability of X_i to explain variations in target variable Y_i, multiple coefficient of determination (R^2) is:

$$R^2 = \frac{A^t\left(X^t X\right)A - n\bar{Y}^2}{y^t y}$$

where $\bar{Y}$ is the average value of *Y*, and *y* is the reduced variable and centered around the average y=(Y_i - $\bar{Y}$). It is important, when using multiple linear regression model, to calculate the adjusted coefficient of determination according to:

$$\bar{R}^2 = 1 - \left(1 - R^2\right)\left(\frac{n-1}{n-k}\right)$$

In a similar way, the absence of dependencies ($Pa_i = \varnothing$) of the variable in question is explained, for each possible dependency relationship, when a value closer to zero or less than zero is obtained for $\bar{R}^2$.

When applying multivariable linear regression, in order to establish correlations between the variables in the domain, it was necessary to define the attributes (metrics) considered for the analysis proposed in this paper. These metrics were selected from the set of tests in the scenarios modeled in OPNET.

Thus, among the metrics provided by OPNET for analysis, seven were defined, which were used in the process of decision making. These metrics are: Throughput, Jitter, Delay Retransmissions, Object Response Time and Data Dropped.

From the definition of the metric (also called criteria) that would be used for decision making, Multivariable Linear Regression was applied. To this end, an application was developed.

Multivariable Linear Regression, when applied on a set of data, extracts the relationship of a given criteria with respect to others. So, this relationship (*A*) will be used as a weight vector and it is the input to multicriteria models of decision making.

The values of *A* were obtained and were normalized to yield the following:

A = [0,06 0,03 0,15 0,41 0,13 0,22]

R^2 (more than 90%) was calculated to verify the quality of linear regression. The extracted weights are throughput, jitter, delay, retransmissions, response time and discarded data.

Thus, by extrapolating the fitted model and assuming that a service provider has more than one choice of access technology for a given scenario, the purpose of this paper is to define what technology should be used.

IV. TESTS TO EVALUATE THE FIRST MILES

From the weights defined, real test scenarios and experiments were performed to test the proposed strategies.

In order to perform measurements in real scenarios, three access technologies were used: PLC, WiMAX, ADSL and 3G. The choice of these different technologies are based on the availability of resources for testing and the focus of these tests on heterogeneous networks since the metrics analyzed should provide different values due to each technology's peculiarities.

WiMAX networks, for example, suffer interference caused by external factors such as distance between antennas and similar frequencies, just like 3G. PLC networks, which use electricity to transfer data, suffer interference caused by devices that operate in frequency bands similar to those used for data transmission. ADSL technology uses fixed telephony lines for data transmission and is characterized by impulsive and background noises.

Thus, scenarios were set for interactive digital TV transmission in LPRAD (Laboratory of Network Planning for High Performance), located at UFPA (Federal University of Pará), in order to test the different types of technologies, as illustrated in Fig. 1, based on four layers already defined. Then, a java applet to obtain the results of the criteria established was employed.

Based on the sampling theory, the tests performed were repeated over fifty times, to obtain an acceptable average for comparison. The average results are shown in Table V.

TABLE V. RESULTS WITH DIFFERENT TECHNOLOGIES

	PLC	WiMAX	ADSL	3G
Average Jitter (ms)	4,8	6,7	3,1	32,1
Average Delay (ms)	16,6	21	13,5	135,00
Average Throughput (Kbps)	716	1436,6	6912,5	1804
Object Response Time (s)	31,6	25,8	21,9	32,1
Number of Data Dropped	2.500	1.800	1.100	3000
Number of Retransmissions	3.000	3.700	2.200	3200

The values shown in Table V show the average of the results obtained from 1 to 40 users. These numbers represent measurements from real-world scenarios at any given time and were used in the decision making process presented in this paper.

From these values, a decision framework using TOPSIS and ELECTRE III was implemented to calculate decision making based on weights previously obtained.

V. APPLYING MULTICRITERIA DECISION MAKING

After evaluating the networks, a decision of which technology to be used follows.

A. TOPSIS Method

For the decision making, TOPSIS method was applied on the results measured from the network (Table V), based on the vector A, which is the weight for each metric evaluated.

An application was used to execute the procedures of TOPSIS. Results show a relative closeness to the ideal solution that ranked the options. The first matrix is the decision matrix that consists of all the criteria and alternatives and their respective measured values (Matrix of table V). Criteria that should be maximized and minimized are also defined.

Once the normalized criteria matrix was obtained, weights were assigned to criteria by multiplying the criteria by the assigned weights. A maximum value (ideal situation, positive) as well a minimum value (non-ideal situation, negative) was determined for each evaluated item. Finally, approximate results (positive and negative) were obtained and the last phase is to generate decreasing order of the obtained values as shown in Table VI.

TABLE VI. TOPSIS RESULT

Alternative	C_i
ADSL2+	0.99999
PLC	0.42772
WiMAX	0.30145
3G	0.26261

Results shown in the Table refer to percentage of indication to use a given return channel (option). So, ADSL2+ showed the best results followed by PLC, WiMAX and 3G.

B. ELECTRE III Method

In order to compare the results from TOPSIS, an algorithm was developed to run ELECTRE III, analytical method. Tests were conducted with the same values used in Table V. The decision matrix, Table VI, is the same used in the previous method.

Relations of subordination were constructed to employ ELECTRE III. Indices of particle agreement, global agreement and credibility were determined according to the methodology of ELECTRE III.

The second step was to classify the alternatives. Based on the credibility indices, relations of subordinations. The final stage was to construct a pre-ordering of intersection. Intersection of two pre-ordering classifies more reliably proving that the options cannot be compared when they exist. After the intersection of all the alternatives, ranking was obtained as shown in Table VII.

TABLE VII. RANKING OF TECHNOLOGIES WITH ELECTRE III

Alternative
ADSL2+
WiMAX
PLC
3G

Just as in the previous case, this also chose ADSL2+ as the best followed by PLC, WiMAX e 3G. If, for some reason (financial, political, availability), the first technology cannot be chosen, the next one is recommended. It is noteworthy that different analytical methods show a same result with slight variations in percentage figures of indicating technologies. Therefore, any method may be employed for decision making.

VI. CONCLUSION

This paper presented a hybrid multicriteria model by combining linear regression (to define weights for the criteria) and TOPSIS and ELECTREII decision making analytical methods (to select the best access technology) to enable planning by service providers considering real scenarios utilizing interactive digital TV of ISDB-T standard. So, service providers may plan/predict the behavior of the services that are offered over the existing telecommunication infrastructure. Thus, they may avoid bottlenecks or idleness in a variety of scenarios.

After careful and a thorough literature review, it was found that the topics as well as open problems cover those discussed in this paper. It is important to point, however, that studies on combining multivariable linear regression with analytical methods for decision making are in preliminary stage to be applied in interactive digital TV environments.

The paper discussed here combined the benefits of each research to cope up with the main deficiencies mentioned in the literature, highlighting: (i) studies that use multicriteria analysis strategies that use analytical methods combined with multilinear linear regression; (ii) characterization of iDTV flow based on measurements obtained from actual scenarios; (iii) employing array of weights analyzed with linear regression and not on specialists as suggested by other methods, AHP for instance; (iv) use of different access technologies already consolidated in the market.

The main results obtained was the heuristic for multicriteria decision that combined linear regression and TOPSIS and ELECTRE III analytical methods for decision making, considering IDTV. The proposed strategy is generic and flexible and can incorporate other parameters and technologies that were not specified in this paper enabling new decisions to different scenarios.

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