Abstract—New added value services delivered over a multi-services IP network require significant changes to its design, including the activation of multiple functions in all active components such as multicast routing, QoS capabilities, security mechanisms... The present article treats multicast routing algorithms and presents the new genetic algorithm BE-MARGAN that aims the construction of a diffusion tree ensuring the interconnection of all members with a minimal delay while optimising the global network bandwidth usage. The article compares also performances of BE-MARGAN with the well known and used routing algorithm RPF for fully evaluation of the scalability of the proposed algorithm.

Keywords—Multicast Routing, Genetic Algorithm, Scalability, Efficiency, Best Effort Routing

I. INTRODUCTION

MULTICAST is defined as the act of sending datagrams to multiple receivers with a single 'transmit' operation.

Initially, the primary advantages of multicasting are the bandwidth optimisation, the reduction of network congestion and server load. In Deering’s model [1], IP multicast is associated with the notion of a group composed of members that can be senders and/or receivers. Three mechanisms are required to support IP multicast and consist mainly of the class D address allocation, the group membership management and the routing process. This last enables routers to compute a distribution tree connecting the sender(s) and receivers of a multicast group, using specific routing algorithms and protocols, such as Reverse Path Forwarding (RPF), Distance Vector Multicast Routing Protocols (DVMRP), Protocol Independent Multicast (PIM), Core Based Trees (CBT)... [1]-[2]-[3]-[4]-[5]-[6]. The tree takes into account the group proprieties (Dynamic size, composition (Number of sources and receivers)) and its topology depends on whether receivers are sparsely or densely distributed throughout the network (Dense-Mode and Sparse-Mode protocols).

II. DISADVANTAGES OF SPT TREES

The most multicast routing protocols actually used in IP networks are RPF based, whose forwarding algorithm performs an RPF check on the incoming interface prior to forward a multicast packet on each downstream interface. To construct a Shortest Path Tree (SPT), RPF performs a mono-objective optimisation of every additive metric such as the administrative cost and the transmission delay. However, RPF is a broadcast method that exploits routing procedures and data structures already available for packet switching to look up state information [2]. It requires thus the acquisition of unicast and multicast topologies. Moreover, the SPT is composed of branches independently computed. Therefore, the acquisition and computation processes leads to a non-optimal utilisation of network bandwidth and decreases the scalability of the routing process [7]-[8]-[9]. Minimising bandwidth requires solving the NP-Complete Steiner tree problem [10].

Due to their robustness, Genetic Algorithms (GAs) are more and more used for solving NP-Complete problems in modern applications of learning, optimization and control in various fields such as business, biology and engineering sciences [11]-[12]. Our previous works proposed GAs performing best effort and constrained routing schemes in unicast environment [13]-[14]-[15]. This article presents the algorithm BE-MARGAN (Best Effort Multicast Adaptive Routing Genetic Algorithm based for interNetworking) used for the construction of a diffusion tree ensuring the interconnection of all members with a minimal delay while optimising the global use of the bandwidth.

III. FUNCTIONNAL STRUCTURE OF THE ALGORITHM

The main goal of BE-MARGAN is to compute a ‘Least Cost Optimisation Routing Tree’ minimising the delay metric between the source and receivers while achieving the global efficiency in term of bandwidth utilisation.

In this context, the BE-MARGAN approach is structured around 3 principal functional processes: the generation of the initial population (I), the genetic operations plus the algorithmic logic to evaluate each candidate tree (II) and finally the computation of the diffusion tree (III) (Fig. 1).

Fig. 1. BE-MARGAN structure.
A. Genetic Encoding

Telecommunication networks are generally modelled as a set of nodes interconnected by communication links where a node could represent a router or an autonomous system (AS). The best effort routing performs a non constrained routing process, thus each link may be characterised by 2 metrics: an ‘Administrative Cost’ (Cost) and the ‘Transmission Delay’ (TD). In BE-MARGAN’s genetic encoding scheme, a gene represents 2 successive routing nodes connected by a transmission link. Each gene has therefore an accessibility state (State) measured by its Cost and TD [13]. A chromosome represents thus a path that is a chain of links connecting routing nodes (Fig. 2).

B. Generation of the Initial Population

BE-MARGAN operates on a population of paths rather individual paths as it is the case of Dijkstra and RPF algorithms [2]. This makes the generation of the initial population an extremely important stage for the accuracy of the computation process. Thus, BE-MARGAN uses a pseudo-random process for the generation of this population by imposing constraints in order to guarantee the feasibility of its paths. A feasible path is continuous, connects source and receiver nodes, is composed of existing links and does not include loops, while avoiding that a link is used more than once. The selection of a link among the outgoing links of a node is done randomly [13]-[14]-[15].

C. Genetic Operations

BE-MARGAN uses 7 genetic operators: Reproduction (Reproduction), Crossover (Crossover), Deletion-Insertion (Deletion-Insertion), Insertion (Insertion), Single Mutate (Mutate), Smoothing (Smooth) and Successive Mutate (Mutate).


Fig. 2. Genetic encoding of a path connecting nodes S and D.

D. BE-MARGAN’s Algorithmic Logic

The studied session concerns a static group composed of a source S and several receivers D. Thus, the construction of a ‘Source Directed Interconnection Topology’ is proposed. For this purpose, BE-MARGAN uses an original algorithmic logic that combines the minimisation of TD with an efficient use of the bandwidth. In this context, a new concept baptised ‘Efficiency SPT’ (ESPT) is introduced. ESPT evaluates the common use of interconnection links by all unicast paths composing the tree. Thus, we have defined ESPT as the ratio of the sum of costs of all unicast paths composing the tree and the sum of costs associated with all its links. So, an ESPT value approaching the value 1 refers to a tree whose paths present quasi-independence, forming thereafter a burst tree using inefficiently the bandwidth. A greater ESPT (ESPT>1) indicates that the tree exploits efficiently interconnection relations existing between its branches. For a tree T, ESPT corresponding to the adhesion of the kth member is:

\[
E_{SPT}(k) = \frac{\sum_{i=1}^{M} Cost_{total}(S \rightarrow D_i)}{\sum_{i=1}^{M} Cost_{total}(D_i)} \quad (2 \leq k \leq M)
\]

k=1 refers to the source node, M is the group size and Hk is the number of links composing the tree T.

E. Tree Computation

To compute the diffusion tree T, BE-MARGAN proceeds in 3 phases. The first one sorts out nodes Di of the group according to their distance to the source S. Thereafter, the algorithm computes the path connecting S to Di (the most distant node to S) according to the minimisation of the TD metric. The obtained path PSiDi is used thereafter as the backbone of the diffusion tree. The 2nd phase forms a population of feasible paths connecting S to Di while minimising the associated TD, using a reduced number of generations. The used evaluation function Fitp is defined as TD_SDi. This population is then subject to the 3rd phase that is an optimisation genetic process selecting the best path P, connecting S to Di which maximises the efficiency of the tree. The used fitness function is then ESPT(S→Di). The 2nd
and 3rd phases are iteratively executed for each receiver $D_i$ ($2 \leq i \leq M$) until the complete adhesion of all members.

IV. SIMULATIONS AND RESULTS

Routing simulations, performed by an own developed simulator, permit to achieve a comparison between RPF and BE-MARGAN. For this purpose, the adhesion of members to the multicast session is simulated and costs of the BE-MARGAN tree, considered as ‘managed by Efficiency’, and the SPT used by RPF, are also computed. The simulation environment is specified by the network size ($N_s$), the group size ($M$), the group members and the nature of the network (Dense or Sparse). The chosen interconnection scheme attributes $Cost_L$ and $TD_L$, randomly distributed, to each link $L_i$ of the network. A node has 4 outgoing links and 4 incoming ones. Genetic parameters of BE-MARGAN are: Generation Gap = 50, Crossover probability = 1, Mutation probability = 0.6, Population size = 50 and Number of generations = 2 for the 2nd phase and = 30 for the 1st and 3rd one. In addition to $E_{SPT}$, the interest is also focused on the evolution of parameters $LFR$ (Last node First node delay Ratio) and Tree_Fitness, defined as follows:

$$LFR(D_i) = \frac{TD(\text{Path}(S \rightarrow D_i))}{TD(\text{Path}(S \rightarrow D_j))}$$

(2)

$$Tree\_Fitness_i(D_i) = \sum_{j=1}^{N} Cost_j(\text{Link}(j))$$

(3)

$LFR(D_i)$ quantifies the evolution of $TD$ of each path leading to $D_i$ in comparison with $TD$ of the 1st path leading to $D_j$. $Tree\_Fitness_i(D_i)$ traduces the cost associated with the transport of multicast packets through the tree whose interconnection links are considered only one time (Number $ng$). Moreover, $E_{SPT}(S \rightarrow D_i)$ underscores the number of links to be used to insure the multicast diffusion. In other words, $E_{SPT}$ and $Tree\_Fitness_i(D_i)$ quantify the total available bandwidth that is necessary to make possible this diffusion.

A. Multicast Diffusion Trees

The studied case is the sequential adhesion of the 15 members in a 35-nodes network ($N_s=35$) (Nodes 35, 33, 30, 28, 24, 23, 19, 15, 10, 14, 25, 17, 21, 13 and 34) and 30 members for $N_s=100$. These nodes are encircled on Fig. 4. The extremities of the tree core are represented by full squares (\{1, 8\} for $N_s=35$ (Fig. 4-a) and \{1, 19\} for $N_s=100$ (Fig. 4-c). RPF computes the shortest unicast paths according to $TD$, starting from $S$ and leading to each of the 15 destination $D_i$. These paths are independent one from each other (Fig. 4-b, Fig. 4-d). BE-MARGAN computes the longest path according to $TD$ that connects $S$ and the most distant member $D_i$ (Node 35 for $N_s=35$). This path is used as a backbone on which the tree is built and to which paths linking to other members are connected. Thus, unicast paths share a set of nodes and links that contribute in the construction of a common tree core for all tree branches. Each node $D_i$ is linked to the tree $T$ through a path connecting $D_i$ to the nearest node belonging to the current tree. Fig. 4 shows trees issued from BE-MARGAN and RPF in networks of 35-nodes and 100 nodes. As it can be noted on Fig. 4-a and Fig. 4-c, BE-MARGAN uses a minimal number of nodes and links, allowing then the optimisation of the bandwidth use in comparison with RPF whose tree is a burst of independent unicast paths (Fig. 4-b and Fig. 4-d).

According to simulations, it is worth noting the BE-MARGAN enhanced results in comparison to RPF and that $E_{SPT}$ (BE-MARGAN) outmatches $E_{SPT}$ (RPF) in all studied cases ($N_s=35$, $E_{SPT}$ (BE-MARGAN)=3.32 (Fig. 4-a) against $E_{SPT}$ (RPF)=1.82 (Fig. 4-b); $N_s=100$, $E_{SPT}$ (BE-MARGAN)=11.298 (Fig. 4-c) against $E_{SPT}$ (RPF)=3.812 (Fig. 4-d)). This significant amelioration of $E_{SPT}$ increases according to the network size (82% and 196% respectively for $N_s=35$ and $N_s=100$). It is explained by the fact that BE-MARGAN approach selects the tree branches on the basis of a differential evaluation that quantifies their contribution in the optimisation of bandwidth usage. In this manner, BE-MARGAN gives the priority to the paths that are able to enhance the global efficiency in comparison with those having the least interconnection cost. In addition, BE-MARGAN is so well adapted to the scalability that it can compute a diffusion tree presenting a better efficiency gain that increases also with the network size.

Fig. 5 shows the evolution of $E_{SPT}$ according to BE-MARGAN and RPF for $N_s=100$ (Trees of Fig. 4-c and 4-d), which illustrates the performance level of both techniques. It is noted that BE-MARGAN enhances the routing process performances thanks to a differential evaluation based on the Efficiency and a better exploitation of the knowledge acquired during the preceding member’s adhesion.

Fig. 6 reports the evolution of $LFR$ parameter according to the adhesion of each member for $N_s=100$. Rg-MC
represents parameters \([seq, rg]\), where \(seq\) is the chronological introduction of a node within the group and \(rg\) denotes its rank in the network. BE-MARGAN permits a 'well controlled' evolution of \(LFR\) since this last has a maximum threshold value equal to 1 (Fig. 6-a). This explains the fact that \(TD\) of each path belonging to the tree cannot exceed \(T_{D1}\) connecting \(S\) with the first member \(D_1\). In case of RPF, each path can present any \(TD\) value. BE-MARGAN builds thus a tree whose \(TD\) does not exceed the threshold \(T_{D_{55}}\).

Fig. 7 reports the evolution of the tree’s total cost (\(Tree_{Fitness}\)). After the adhesion of the last member (Node 55), \(Tree_{Fitness}\) values corresponding to BE-MARGAN and RPF are respectively 216.149 and 557.311.

![Fig. 5. Evolution of \(E_{SR}\); \(N_5 = 100\).](image)

![Fig. 6. Evolution of \(LFR\); \(N_5 = 100\).](image)

![Fig. 7. Evolution of \(Tree_{Fitness}\); \(N_5 = 100\).](image)

Even if BE-MARGAN has initially a greater cost due to the use of the longest path as a backbone of the diffusion tree, it constructs a tree with a decreasing cost as long as the adhesion process progresses. In other words, BE-MARGAN consummes a less bandwidth in order to insure the multicast diffusion. These results confirm well the advantage and the gain relative to the proposed evoluzionnary approach.

V. CONCLUSION

This paper describes a multicast routing algorithm, BE-MARGAN that uses Genetic Algorithms as an optimisation tool to allow an ‘auto-discovery’ of the network resources and the adaptation to the dynamic network state fluctuation. Moreover, it proposes an original algorithmic logic that combines the minimisation of transmission delay to an efficient use of the network bandwidth. In this context, a new concept, baptised ‘Efficiency SPT' \((E_{SPT})\), is introduced to evaluate the fitness of each candidate path. Performances of BE-MARGAN are compared with those of the RPF algorithm in 2 different networks for fully scalability evaluation. The results show and confirm the advantage and the gain allowed by the proposed evolutionnary approach.

REFERENCES