Genetic Algorithm and Pareto Optimum Based QoS Multicast Routing Scheme in NGI*

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Abstract. In this paper, a QoS (Quality of Service) multicast routing scheme in NGI (Next Generation Internet) is proposed based on genetic engineering and microeconomics. It can not only deal with network status inaccuracy, but also help prevent network overload and meet with intra-group fairness, trying to find a multicast routing tree with bandwidth, delay, delay jitter and error rate satisfaction degree, bandwidth availability degree and fairness degree achieved or approached Pareto optimum.

1 Introduction

NGI (Next Generation Internet) should provide the user with the end-to-end QoS (Quality of Service) support. However, it is hard to describe the network status accurately [1]. With gradual commercialization of the network operation, paying for network usage become necessary, QoS pricing and accounting should be provided [2]; for multicast applications, intra-group fairness should be considered [2]. In addition, sometimes network overload happened and network performance lowered sharply, such phenomenon should be prevented or alleviated. Support from QoS routing should be provided to help solve these problems [2].

QoS multicast routing is NP-complete [3] and can be solved by heuristic or intelligent algorithms. In this paper, a GA and Pareto optimum [4] based QoS multicast routing scheme is proposed. It can deal with network status inaccuracy by introducing several QoS constraint satisfaction degrees, meet with intra-group fairness by introducing fairness degree, help to prevent network overload by introducing bandwidth availability degree. It tries to find a multicast routing tree based on GA, achieving or approaching Pareto optimum on their QoS constraint satisfaction degrees, bandwidth availability degree and fairness degree.

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2 Problem Formulation

2.1 Symbol Definition

In this paper, use G to denote a graph, V node set in G, E edge set in G, v_s multicast source node, M multicast destination node set($M \subseteq V$), v_t multicast destination node($v_t \in M$, $t = 1,2,3,...,|M|$), T tree, p a path in T , p_t a path to v_t in T , l link, bc_l total bandwidth of l , bw_l available bandwidth of l , dl_l delay of l , jt_l delay jitter of l , ls_l error rate of l , B multicast bandwidth constraint, D multicast delay constraint, J multicast delay jitter constraint, L multicast error rate constraint; $bw_p = \min_{l \in p}\{bw_l\}$ bandwidth of p , $dl_p = \sum_{l \in p} dl_l$ delay of p , $jt_p = \sum_{l \in p} jt_l$ delay jitter of p , $ls_p = 1 - \prod_{l \in p}(1 - ls_l)$ error rate of p , $bw_T = \min_{l \in T}\{bw_l\}$ available bandwidth of T , $dl_T = \max_{p \in T}\{dl_p\}$ delay of T , $jt_T = \max_{p \in T}\{jt_p\}$ delay jitter of T , $ls_T = \max_{p \in T}\{ls_p\}$ error rate of T ; $Pr_p(bw_p \geq B)$ bandwidth satisfaction degree of p (probability of bw_p bigger than B), $Pr_p(dl_p \leq D)$ delay satisfaction degree of p , $Pr_p(jt_p \leq J)$ delay jitter satisfaction degree of p , $Pr_p(ls_p \leq L)$ error rate satisfaction degree of p , $Pr_T(bw_T \geq B)$ bandwidth satisfaction degree of T , $Pr_T(dl_T \leq D)$ delay satisfaction degree of T , $Pr_T(jt_T \leq J)$ delay jitter satisfaction degree of T , $Pr_T(ls_T \leq L)$ error rate satisfaction degree of T , bwr_T bandwidth availability degree of T (indicating network load level), g_T fairness degree of T (indicating intra-group fairness), bws_t bandwidth which the network should allocate to v_t , bwa_t bandwidth which v_t actually get from network, uc_t cost which v_t is willing to pay, η bandwidth price, μ QoS multicast routing request arrival rate, hop hop number of the path.

2.2 Mathematical Model

Given v_s and M , find a multicast routing tree $T(W, F)$, $M \subseteq W \subseteq V$, $F \subseteq E$, making its bandwidth satisfaction degree, delay satisfaction degree, delay jitter satisfaction degree, error rate satisfaction degree, bandwidth availability degree and fairness degree achieve or approach Pareto optimum without any of them below the prescribed threshold. The mathematic model is described as follows:

$$minmize\left\{\sum_{i=1}^{6}\frac{q_i}{Pr_{Ti}}\right\} \tag{1}$$

$$Pr_{Ti} \geq \Delta_i \tag{2}$$

Here, Pr_{T1} denotes $Pr_T(bw_T \geq B)$, Pr_{T2} denotes $Pr_T(dl_T \leq D)$, Pr_{T3} denotes $Pr_T(jt_T \leq J)$, Pr_{T4} denotes $Pr_T(ls_T \leq L)$, Pr_{T5} denotes bwr_T and Pr_{T6} denotes g_T ; q_i denote application preference weights to bandwidth satisfaction degree, delay satisfaction degree, delay jitter satisfaction degree, error rate satisfaction degree, bandwidth availability degree and fairness degree respectively, indicating whether one or some of them should be considered with priority when routing, and their values are determined by application nature; Δ_i are prescribed threshold between 0 and 1.

This is NP-complete [3] and solved base on GA.

3 Routing Scheme Description

3.1 Parameter Design

According to [1], suppose bw_l obey uniform distribution between $[bw_l - \Delta bw_l, bw_l + \Delta bw_l]$ and Δbw_l is the maximum possible variation before next update of network status, $Pr_p(bw_p \geq B)$ and $Pr_T(bw_T \geq B)$ are computed as follows:

$$Pr_p(bw_p \geq B) = \prod_{l \in p} \min\left(\max\left(0, \frac{bw_l + \Delta bw_l - B}{2\Delta bw_l} \right), 1 \right) \tag{3}$$

$$Pr_T(bw_T \geq B) = \prod_{p \in T} Pr_p(bw_p \geq B) \tag{4}$$

Consider network links as service queues for sending packets and their services are independent, that is, μ obeys Poisson distribution [5] with parameter λ between period $(\theta, \theta + \Delta\theta)$, $\lambda > 0$. Because delay of each hop along the path may be different, it is necessary to estimate (hop, D, μ) simultaneously. In this paper, Erlang distribution is adopted and $Pr_p(dl_p \leq D)$ is computed as follows:

$$Pr_p(dl_p \leq D) = 1 - \sum_{k=0}^{hop-1} \frac{(\mu D)^k}{k!} e^{-\mu D} \tag{5}$$

In the worst case, each path in multicast tree is edge disjoint. In this paper, $Pr_T(dl_T \leq D)$ under such case is used as its estimation and computed as follows:

$$Pr_T(dl_T \leq D) = \prod_{p \in T} Pr_p(dl_p \leq D) \tag{6}$$

The proposed scheme encourages constructing a tree with fewer edges, helping lower its delay and its occupied resource and thus reduce network load.

$Pr_p(jt_p \leq J)$, $Pr_T(jt_T \leq J)$, $Pr_T(ls_T \leq L)$ and $Pr_T(ls_T \leq L)$ are computed as follows respectively:

$$Pr_p(jt_p \le J) = 1 - \sum_{k=0}^{hop-1} \frac{(\mu J)^k}{k!} e^{-\mu J} \tag{7}$$

$$Pr_T(jt_T \le J) = \prod_{p \in T} Pr_p(jt_p \le J) \tag{8}$$

$$Pr_T(ls_T \le L) = 1 - \sum_{k=0}^{hop-1} \frac{(\mu L)^k}{k!} e^{-\mu L} \tag{9}$$

$$Pr_T(ls_T \le L) = \prod_{p \in T} Pr_p(ls_p \le L) \tag{10}$$

bwr_T should reflect network resource occupancy:

$$bwr_T = \min_{l \in T} \left\{ \frac{bw_l}{bc_l} \right\} \tag{11}$$

bws_t should be proportional to uc_t:

$$bws_t = \frac{uc_t}{\eta} \tag{12}$$

However, due to difficulty in exact measurement on network status, bwa_t may be unequal to bws_t. The expectation of bwa_t is computed as follows:

$$E(bwa_t) = \min_{l \in p_t}\{ \underset{bw_l > B}{E}(bw_l) \} \tag{13}$$

$$E(bw_l) = \begin{cases} 0 & bw_l + \Delta bw_l < B \\ \dfrac{\max(bw_l - \Delta bw_l, B) + (bw_l + \Delta bw_l)}{2} & \text{otherwise} \end{cases} \tag{14}$$

The difference between bws_t and bwa_t and its expectation and variance are computed as follows:

$$\Delta w_t = bws_t - E(bwa_t) \tag{15}$$

$$E(\Delta w_t) = \sum_{l \in T} \frac{\Delta w_t}{|M|} \tag{16}$$

$$s_T^2(\Delta w_t) = \frac{1}{|M|} \sum_{i=1}^{|M|} [\Delta w_i - E(\Delta w_i)]^2 \tag{17}$$

Fairness degree is computed as follows:

$$bws_t = \frac{uc_t}{\eta} \tag{18}$$

The bigger the g_T, the smaller the Δw_t, the higher the intra-group fairness.

3.2 Algorithm Design

3.2.1 Initial Population Generation and Chromosome Encoding

Each chromosome in population corresponds to a multicast routing tree. P_s trees are generated by random depth first search algorithm [6] to form the initial population, P_s is population size. Binary encoding scheme is adopted for chromosome, mapping its corresponding tree to a string containing path from v_s to each v_t .

3.2.2 Selection, Crossover and Mutation

The hybrid chromosome selection strategy combining with roulette wheel and elite [7] is adopted. The elite is set to conserve the current optimal chromosome. Only when the optimal chromosome in the offspring population is better than the current elite, does the corresponding replacement happen. The single-point crossover and random mutation by certain probability is used to generate new chromosome [7] in this paper.

3.2.3 Sharing Operation

Sharing operation [8] is used to promote chromosome diversity in population to speedup convergence to the optimal solution. Suppose x_i and x_j are two chromosomes. $\sigma_{bw_{x_i,y_j}}$, $\sigma_{dl_{x_i,y_j}}$, $\sigma_{jt_{x_i,y_j}}$, $\sigma_{ls_{x_i,y_j}}$, $\sigma_{bwr_{x_i,y_j}}$ and $\sigma_{g_{x_i,y_j}}$ denote distance of bandwidth satisfaction degree, delay satisfaction degree, delay jitter satisfaction degree, error rate satisfaction degree, bandwidth availability degree and fairness degree between x_i and x_j respectively and are computed as follows:

$$\sigma_{bw_{xi,xj}} = Pr_{T\,x_i}(bw_T \geq B) - Pr_{T\,x_j}(bw_T \geq B) \tag{19}$$

$$\sigma_{dl_{x_i,x_j}} = Pr_{T\,x_i}(dl_T \leq D) - Pr_{T\,x_j}(dl_T \leq D) \tag{20}$$

$$\sigma_{jt_{x_i,x_j}} = Pr_{T\,x_i}(jt_T \leq J) - Pr_{T\,x_j}(jt_T \leq J) \tag{21}$$

$$\sigma_{ls_{x_i,x_j}} = Pr_{T\,x_i}(ls_T \leq L) - Pr_{T\,x_j}(ls_T \leq L) \tag{22}$$

$$\sigma_{bwr_{x_i,x_j}} = bwr_{T_{x_i}} - bwr_{T_{x_j}} \tag{23}$$

$$\sigma_{g_{x_i,x_j}} = g_{T_{x_i}} - g_{T_{x_j}} \tag{24}$$

Use $d(x_i, x_j)$ denote distance between x_i and x_j , $d_{\max}$ denote the maximum distance between any two chromosomes, and are computed as follows:

$$d_{x_i,x_j} = \sqrt{(\sigma_{bw_{x_i,x_j}})^2 + (\sigma_{dl_{x_i,x_j}})^2 + (\sigma_{jt_{x_i,x_j}})^2 + (\sigma_{ls_{x_i,x_j}})^2 + (\sigma_{bwr_{x_i,x_j}})^2 + (\sigma_{g_{x_i,x_j}})^2} \tag{25}$$

$$d_{\max} = \frac{1}{2}\sqrt{(\sigma_{bw_{\max}})^2 + (\sigma_{dl_{\max}})^2 + (\sigma_{jt_{\max}})^2 + (\sigma_{ls_{\max}})^2 + (\sigma_{bwr_{\max}})^2 + (\sigma_{g_{\max}})^2} \tag{26}$$

$$\sigma_{bw_{\max}} = Pr_{T\max}(bw_T \geq B) - Pr_{T\min}(bw_T \geq B) \tag{27}$$

$$\sigma_{dl_{\max}} = Pr_{T\max}(dl_T \le D\ ) - Pr_{T\min}(dl_T \le D) \tag{28}$$

$$\sigma_{jt_{\max}} = Pr_{T\max}(jt_T \le J) - Pr_{T\min}(jt_T \le J) \tag{29}$$

$$\sigma_{ls_{\max}} = Pr_{T\max}(ls_T \le L) - Pr_{T\min}(ls_T \le L) \tag{30}$$

$$\sigma_{bwr_{\max}} = bwr_{T\max} - bwr_{T\min} \tag{31}$$

$$\sigma_{g_{\max}} = g_{T\max} - g_{T\min} \tag{32}$$

In this paper, the following exponent sharing function [8] is adopted:

$$s(x_i, x_j) = \begin{cases} 1 - \left[\dfrac{d(x_i, x_j)}{d_{\max}} \right]^{\alpha} & d(x_i, x_j) < d_{\max} \\ 0 & d(x_i, x_j) \ge d_{\max} \end{cases} \tag{33}$$

3.2.4 Fitness Function

It is Computed as Follows:

$$f(x_i) = \sum_{k=1}^{6} \frac{q_k}{ff_{\tau k}(x_i)} \tag{34}$$

$$ff_{\tau k}(x_i) = \frac{f_{\tau k}(x_i)}{\sum_{j=1}^{n} s(x_i, x_j)} \tag{35}$$

$$f_{\tau k}(x_i) = Pr_{x_i k} \tag{36}$$

$$f_{(\tau+1)k}(x_i) = f_{\tau k}(x_i)\phi(\tau+1) \tag{37}$$

$$\phi(\tau+1) = \begin{cases} (1/\beta_1) & f_{(\tau+1)k}(x_i) < f_{\tau k}(x_i) \\ \beta_2 & f_{(\tau+1)k}(x_i) > f_{\tau k}(x_i) \\ 1 & f_{(\tau+1)k}(x_i) = f_{\tau k}(x_i) \end{cases} \tag{38}$$

Here, $k = 1,2,...,6$; τ is evolution times by far; $\phi(\tau+1)$ is adaptive penalty factor, regulating fitness value to accelerate convergence to the optimal solution; $\beta_1 > 1$, $\beta_2 > 1$, $\beta_1 \ne \beta_2$. Obviously, the smaller the fitness value, the higher the bandwidth satisfaction degree, delay satisfaction degree, delay jitter satisfaction degree, error rate satisfaction degree, bandwidth availability degree and fairness degree of the multicast routing tree, the more nearer to Pareto optimum even achieve Pareto optimum, at the same time the more its dissimilarity to other chromosomes.

3.2.5 Pareto Optimal Solution Set

Chromosome comparison rules are defined as follows.

Rule 1: If all $Pr_{x_i k} \le Pr_{x_j k}$ and at least there exists such one k that $Pr_{x_i k} \ne Pr_{x_j k}$ $(k = 1,2,...,6)$, x_i is considered to be inferior to x_j.

Rule 2: If all $Pr_{x_i k} = Pr_{x_j k}$ $(k = 1,2,...,6)$, x_i is considered to be equal to x_j.

Rule 3: If both rule 1 and 2 not satisfied, x_i is considered to be equivalent to x_j.

Pareto optimal solution set update rules are defined as follows.

Rule 1: If there exist chromosomes inferior to a given chromosome, delete such ones and add the given chromosome into the Pareto optimal solution set.

Rule 2: If a given chromosome is equivalent to all ones in the Pareto optimal solution set, add the given one into the Pareto optimal solution set.

Rule 3: If rule 1 and 2 not satisfied, do not modify the Pareto optimal solution set.

3.2.6 Procedure Description

The procedure of the proposed scheme is described as follows:

Step0: Set P_s, the maximum evolution times N, the maximum times of the elite remaining invariable M; let the counter of evolution times $i = 0$, the counter of times of the elite remaining invariable $j = 0$, Pareto optimal solution set $\Lambda = \Phi$.

Step1: According to section 3.2.1, generate initial population $P = \{x_1, x_2, ..., x_{P_s}\}$. Choose one x_r from P randomly as the current elite, put it into the safety valve, and add x_r into Λ, $r = 1,2,..., P_s$.

Step2: $i = i + 1$; if $i \le N$, compute fitness values of all chromosomes in P according to formula (3)-(38), go to Step 3; otherwise, go to Step 6.

Step 3: Do chromosome selection, crossover, and mutation to generation the offspring population according to section 3.2.2.

Step4: Compare chromosomes in the offspring population with the ones in Λ and update Λ correspondingly according to section 3.2.5.

Step5: Find the chromosome which the smallest fitness value in Λ and compare it with the current elite: if the fitness value of the former is smaller than that of the latter, the latter is replaced by the former and $j = 0$, otherwise $j = j + 1$; if $j = M$, go to Step 6, otherwise replace P with the offspring population and go to Step 2.

Step6: Use the elite as the problem solution and output it, the algorithm ends.

4 Conclusion

Simulations have been done on NS2 (Network Simulator) platforms [9], showing that the proposed scheme is effective [10]. In future, the proposed scheme will be improved on its practicability with its prototype systems developed. In addition, taking the difficulty on exact and complete expression of the user QoS requirements into account, how to tackle the fuzziness of both the user QoS requirements and the network status in the proposed scheme is another emphasis of our future research.

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