A Small-World Optimization Algorithm Based and ABC Supported QoS Unicast Routing Scheme[*]

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Abstract. In this paper, by introducing knowledge of fuzzy mathematics, probability theory and gaming theory, a QoS unicast routing scheme with ABC supported is proposed based on small-world optimization algorithm. Under inaccurate network status information and imprecise user QoS requirement, the proposed scheme uses the range to describe the user QoS requirement and the edge parameter, introduces the user satisfaction degree function, the edge evaluation function and the path evaluation function, trying to find a QoS unicast path with Pareto optimum under Nash equilibrium on both the network provider utility and the user utility achieved or approached. Simulation results have shown that it is both feasible and effective with better performance.

Keywords: NGI(Next Generation Internet); QoS(Quality of Service); Unicast routing; ABC (Always Best Connected); Small-world optimization algorithm; Nash equilibrium; Pareto optimum.

1 Introduction

Recently, with the growth and convergence of Internet, multimedia content and mobile communication technology, NGI (Next Generation Internet) is becoming an integrated network [1-4] converged seamlessly by heterogeneous multi-segment multi-provider sub-networks, such as terrestrial-based, space-based, fixed and mobile sub-networks, etc. Its backbone and access links become diversified. Several kinds of links may coexist on each hop for the user to choose along the end-to-end path. It is possible for the user to be ABC (Always Best Connected) [3-4] to NGI in the course of communication, that is, the user can connect with NGI anytime, anywhere in the currently best way and can switch to the better way adaptively and transparently whenever it comes forth, and thus the so-called global QoS (Quality of Service) roaming should be supported seamlessly [5].

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In NGI, QoS routing is essential and ABC should be supported [4]. However, some characteristics of NGI, such as its heterogeneity and dynamics, influence of terminal and even network mobility, unavoidable message transfer delay and its uncertainty, etc., make it hard to describe the network status used when routing in NGI exactly and completely. On the other hand, the user QoS requirements are affected largely by a lot of subjective factors and often can not be expressed accurately, therefore the flexible QoS description should be provided. ABC means a user can get the best available connection anytime, anywhere, however, ‘best’ itself is a fuzzy concept, depending on many factors, such as user QoS requirement, cost a user willing to pay, user preference, terminal ability and access network availability, etc. In addition, with the gradual commercialization of network operation, ABC is not a user's own wishful thinking and thus need to consider both the network provider profit and the user profit with both-win supported [6].

It has been proved that the problem of finding a path subject to constraints on two or more additive or multiplicative metrics in any possible combination is NP-complete [7]. There are already many heuristic and intelligent optimization algorithms used to solve this problem. In [8], the edges that do not meet with the bandwidth constraint are cut off from the graph at first, and then Dijkstra algorithm [9] is used to find the bandwidth-constrained least-delay path with delay as weight. In [10], a distributed heuristic algorithm is proposed, which constructs a delay vector and a cost vector for each node to help find the path. In [11], a comprehensive parameter that is the probabilistic combination of cost and delay is introduced and used when routing. In [12], QoS parameters are defined as path-correlative non-negative variables and are divided into two classes: QoS sensitive and non-sensitive, so that the routing computation can be simplified. In [13], a route pre-computation scheme is proposed based on Bellman-Ford algorithm [14], and the substantial improvement in terms of computational complexity has been achieved by quantizing the cost function. In [15] and [16], a distributed delay-constrained algorithm and a multi-constrained source routing algorithm are proposed respectively. In [17], several pseudo-polynomial time algorithms have been proposed to solve the delay-constrained least-cost routing problem. On the other hand, many optimization algorithms, such as genetic algorithm, ant colony algorithm, and simulated annealing algorithm, have been used to solve QoS routing problem in order to find the optimal or near-optimal QoS route [18-20].

However, the above proposed schemes do not consider sufficiently realizing a QoS unicast routing mechanism with both-win of the network provider and the user supported under imprecise network status and inaccurate user QoS requirement from ABC viewpoint. In this paper, by introducing knowledge of fuzzy mathematics, probability theory and gaming theory, a QoS unicast routing scheme with ABC supported is proposed. In order to deal with imprecise network status information and flexible user QoS requirement, it uses range to describe the user QoS requirement and the edge parameter and introduces the user satisfaction degree function, the edge evaluation function and the path evaluation function. Based on small-world optimization algorithm, it tries to find a QoS unicast path with Pareto optimum under Nash equilibrium on both the network provider utility and the user utility achieved or approached. Simulation results have shown that the proposed scheme is both feasible and effective with better performance.

2 Problem Description

In this paper, the adopted network model, routing request, edge parameter probability model, user satisfaction degree function, edge and path evaluation function, gaming analysis and mathematical model are the same as those in [21]. Due to limited space, please refer to [21] for their detailed descriptions.

3 Algorithm Design

Small-world optimization algorithm [22] optimizes its solution searching process based on small world phenomenon, regarding optimization process as information transfer from a candidate solution to the optimized solution in searching space. The proposed QoS unicast routing scheme based on small-world optimization algorithm is described as follows.

3.1 Basic Definition

In Small-world optimization algorithm, call a candidate solution as a transfer node. In this paper, s represents a transfer node and S represents a transfer node set, $s \in S$. $s = s_1 s_2 \cdots s_{|E|}$ adopts binary encoding, if one bit is 0, its correspond edge is in s , otherwise not in s . A node is generated randomly, that is, each bit of its codes is set to be 0 or 1 randomly.

The fitness function of s is defined as follows:

$$FT(s) = \frac{1}{EC_P(s)} \cdot \sum_{e_l \in P} \frac{NE_l}{PA_{xy}^l} \quad . \tag{1}$$

$$NE_l = \begin{cases} 1 & \text{Nash equilibrium} \\ >1 & \text{otherwise} \end{cases} \quad . \tag{2}$$

Obviously, the smaller its fitness value, the better the solution.

The information transfer target set is defined as follows:

$$T = \{ s \mid (s \in I) \wedge (FT(s) = FT^*) \} \quad . \tag{3}$$

Here, I is solution space, FT^* is the smallest fitness value of solutions in I .

Define the distance between two nodes as follows:

$$d(s_b, s_c) = \|s_b - s_c\| \quad . \tag{4}$$

Here, $s_b, s_c \in S$, $\|s_b - s_c\|$ is the Hamming distance between s_b and s_c .
Define the set of solutions in its ℓ neighborhood of s_b as follows:

$$\zeta^{\ell}(s_b) = \left\{ s_c \middle| (s_c \in S) \wedge (0 < \|s_b - s_c\| \le \ell) \right\} \quad . \tag{5}$$

Then, use $\overline{\zeta^{\ell}(s_b)}$ to represent the set of solutions not in its ℓ neighborhood of s_b .

3.2 Local Short Conjunctive Search Operator

When ℓ is small, this operator is used to transfer information from $s_b(j)$ to $s_b(j+1)$ which is the closest to T in $\zeta^{\ell}(s_b(j))$, denoted as $s_b(j+1) \leftarrow \Psi(s_b(j))$. In this paper, take $N_{len}(j) < \left|\zeta^{\ell}(s_b)\right|$ nodes from $\zeta^{\ell}(s_b(j))$ randomly to construct a temporary local transfer network for local search. It is described in algorithm 3.1.

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Algorithm 3.1  Set $N_{len}(j) < \left|\zeta^{\ell}(s_b)\right|$ ; $s_b(j+1) \leftarrow s_b(j)$
$c \leftarrow 0$
repeat
$s'_b(j) \leftarrow s_b(j) \times 0$
select $f (0 < f \le \ell)$ bits from $s'_b(j)$ randomly and set them to be 1
$s'_b(j) \leftarrow s_b(j) \neg 2 \times (s_b(j) \otimes s'_b(j)) \oplus s'_b(j)$
if $FT(s'_b(j)) < FT(s_b(j+1))$
    $s_b(j+1) \leftarrow s'_b(j)$
endif
$c \leftarrow c+1$
until $c = N_{len}(j)$
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Here, j is the iteration times, $s_b(j) \times 0$ is to obtain a temporary string with each bit to be set 0, $\oplus$ represents "add bit by bit", $\neg$ represents "subtract bit by bit", and $\otimes$ represents "multiply bit by bit".

3.3 Random Long Conjunctive Searching Operator

When ℓ is large, this operator is used to select a node $s'_b(j)$ in $\overline{\zeta^{\ell}(s_b)}$ randomly by a preset probability as information transfer object node of $s_b(j)$, which is denoted as $S'(j) \leftarrow \Gamma(S(j))$. It is described in algorithm 3.2.

Algorithm 3.2 Set global long conjunctive probability p_{len} and ℓ

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1: $b \leftarrow 0$
2: repeat
3:   $s'_b(j) \leftarrow s_b(j)$
4:   $p \leftarrow rand(0-1)$
5:   if $p_{len} < p$ and $s_b(j)$ is not the optimum in the current node set
6:     generate two integers $\mu$ and $\nu$ randomly, $1 \le \mu < \nu \le len$, $|\mu - \nu| > \ell$
7:     $s_b(j) \leftarrow s'_b(j)\big|_{\mu}^{\nu}$
8:   endif
9:   $b \leftarrow b+1$
10: until $b = N$
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In the above, the forth sentence is to generate a random number which is evenly distributed between 0 and 1, the seventh sentence is to reverse the bit order from the μth to the νth bit in $s'_b(j)$.

3.4 Algorithm Procedure

The procedure of the proposed QoS unicast routing algorithm is described as follows:

Step1: Set the node set size to be N ; set $p_{|E|}$ and ℓ.

Step2: Generate the initial node set $S(0) = \{s_1(0), s_2(0), \cdots, s_N(0)\}$ randomly according to section 3.1, i.e., generate N initial unicast paths.

Step3: For each node $s_b(0) \in S(0)$, compute the user utility and the network provider utility on each edge according to formula (23) and (25) in [21] , and play game according to section 2.4 in [21].

Step4: Compute $FT(s_b(0))$ for each node $s_b(0) \in S(0)$.

Step5: Judge whether $s_b(0)$ meets the constraints defined by formula (36)-(39) in [21] or not: if not so, regenerate it and go to Step4.

Step6: Record the best fitness value FT^b of the nodes in the current node set.

Step7: Set the iteration times to be Itr , set ε , $j = 0$.

Step8: If $j \le Itr$ and $\left|FT^* - FT^b\right| \le \varepsilon$ (termination criteria)is not met, go to Step9, otherwise go to Step17.

Step9: Construct the temporary node set $S'(j)$, $S'(j) \leftarrow S(j)$.

Step10: execute the algorithm 3.2, $S'(j) \leftarrow \Gamma(S'(j))$.

Step11: $b = 0$

Step12: execute the algorithm 3.1 to $s_b(j)$, $s'_b(j+1) \leftarrow \Psi(s'_b(j))$, $s'_b(j) \in S'(j)$.

Step13: If $FT(s'_b(j+1)) < FT(s_b(j))$, $s_b(j+1) \leftarrow s'_b(j+1)$, otherwise $s_b(j+1) \leftarrow s_b(j)$.

Step14: $b = b+1$. If $b < N$, go to Step12, otherwise go to Step15.

Step15: Update FT^b with the best fitness value of the nodes in the current node set.

Step16: $j = j+1$, go to Step8.

Step17: Output the optimal node as the problem solution, the algorithm ends.

Specially, when $0 < \left|FT^*\right| < 1$, termination criteria changes to $\left|FT^* - FT^b\right| < \varepsilon\left|FT^*\right|$.

4 Simulation Research

Simulations of the proposed QoS unicast routing scheme have been done on NS2 (Network Simulator 2)[23] and simulation results have shown that it has better performance when its main parameters are set to be the following values[22]: ε=0.0005, k=2 , σ_1=3 , σ_2=3 , α_B=1/3 , α_D=1/3 , α_L=1/3 , n=6 , m=4 , δ=0.8 , $k_1 = 0.6$, $k_2 = 0.4$, λ_1=0.6 , λ_2=0.6 , ρ=0.5 , α=0.5 , β=0.5 .

Assume that there are three network providers providing satellite, cellular and fixed links respectively, that is, there are three kinds of links for a user to choose on each hop along the path. The proposed scheme, the proposed microeconomics based fuzzy unicast QoS routing scheme in [24], and the unicast routing scheme based on Dijkstra algorithm [8] have been simulated on some physical and virtual network topologies, called A, G and D schemes below for short. Compared with A scheme, G scheme takes imprecise network status and both-win of the network provider utility and the user utility into account but does not consider imprecise user QoS requirement and ABC. Simulation results have shown that A scheme has the better performance. Comparison results on QoS unicast routing request succeeded rate(RSR), user utility(UU), satellite link provider utility(SPU), cellular link provider utility(CPU), fixed link provider utility(FPU), network provider utility(NU=SPU+CPU+FPU), comprehensive utility(CU=UU+NU), Pareto optimum ratio under Nash equilibrium(PRN) achieved by A, G and D schemes over CERNET topology(T1), CERNET2 topology(T2), GÉANT topology(T3) and one virtual topology(T4, generated by Waxman2[25] with average node degree 3.5) are shown in Table 1. From Table 1, it can be concluded that the proposed scheme has the better performance, especially when topologies are complex.

Table 1(1). Comparison Results.

Topology	T1	T2
Metrics	A:G:D	A:G:D
RSR	1.1624:1.1136:1.0000	1.1427:1.0848:1.0000
UU	1.1327:1.0816:1.0000	1.1029:1.0937:1.0000
SPU	1.0657:1.0411:1.0000	1.0531:1.0384:1.0000
CPU	1.1576:1.1295:1.0000	1.1465:1.1152:1.0000
FPU	1.1253:1.0773:1.0000	1.1187:1.0692:1.0000
NU	1.1369:1.0873:1.0000	1.1057:1.0632:1.0000
CU	1.1347:1.0866:1.0000	1.1036:1.0793:1.0000
PRN	4.4091:3.6819:1.0000	4.3519:3.7262:1.0000

Table 1(2). Comparison Results.

Topology	T3	T4
Metrics	A:G:D	A:G:D
RSR	1.1935:1.1218:1.0000	1.2129:1.1694:1.0000
UU	1.1737:1.1033:1.0000	1.1859:1.1097:1.0000
SPU	1.0814:1.0548:1.0000	1.0894:1.0627:1.0000
CPU	1.1859:1.1348:1.0000	1.2065:1.1674:1.0000
FPU	1.1468:1.0961:1.0000	1.1722:1.1283:1.0000
NU	1.1562:1.1409:1.0000	1.1757:1.1376:1.0000
CU	1.1631:1.1274:1.0000	1.1991:1.1184:1.0000
PRN	4.8439:3.9644:1.0000	5.2161:4.2493:1.0000

5 Conclusion

In this paper, by introducing knowledge of fuzzy mathematics, probability theory and gaming theory, a QoS unicast routing scheme with ABC supported is proposed based on small-world optimization algorithm. Under imprecise network status and inaccurate user QoS requirement, it tries to search for a QoS unicast path to make both the network provider utility and the user utility achieve or approach Pareto optimum under Nash equilibrium. Simulation results have shown that the proposed scheme is both feasible and effective with better performance. In future, our study will focus on improving its practicality, developing its prototype system and extend it to multicast scenario.

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