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An improved quantum-inspired evolutionary algorithm for coding resource optimization based network coding multicast scheme

Huanlai Xing, Yuefeng Ji *, Lin Bai, Yongmei Sun

Key Laboratory of Information Photonics and Optical Communications, Ministry of Education, Beijing University of Posts and Telecommunications, Beijing 100876, PR China

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This paper investigates how to minimize the required coding resources in network-coding-based multicast scenarios. An evolutionary algorithm (MEQEA) is proposed to address the above problem. Based on quantum-inspired evolutionary algorithm (QEA), MEQEA introduces multi-granularity evolution mechanism which allows different chromosomes, at each generation, to have different rotation angle step values for update. In virtue of this mechanism, MEQEA significantly improves its capability of exploration and exploitation, since its optimization performance is no longer overly dependant upon the single rotation angle step scheme shared by all chromosomes. MEQEA also presents an adaptive quantum mutation operation which is able to prevent local search efficiently. Simulations are carried out over a number of network topologies. The results show that MEQEA outperforms other heuristic algorithms and is characterized by high success ratio, fast convergence, and excellent global-search capability.

1. Introduction

Network coding technology is a new communication paradigm and is superior to traditional routing in many aspects, especially in increasing multicast throughput [1,2]. Traditional routing adopts *store-and-forward* data processing scheme with which any intermediate node simply replicates the incoming data information (namely, data packets) and forwards a copy to its downstream node(s). However, the maximum throughput of a multicast scenario could not be often achieved by using such data processing scheme [1,2]. With *code-and-forward* data processing scheme at network-layer, network coding allows any intermediate node to combine (also called code) data information received from different incoming links and to output the coded information if necessary, being able to obtain a multicast throughput that is maximized according to MAX-FLOW MIN-CUT theorem [2].

Fig. 1 shows the advantages of network coding compared to traditional routing with respect to the achieved maximum multicast throughput. Fig. 1(a) shows a network with source s and two sinks y, z. Each direct link has a capacity of one bit per unit time. Source s expects to send two bits, a and b, to y and z. According to the MAX-FLOW MIN-CUT theorem, the min cut $C_{\min}$ between s and the set of destinations y, z is two bits per unit time, which means the maximum multicast throughput from s to y (or to z) should be two bits per unit time. However, if traditional routing is adopted, the multicast throughput is 1.5 bits information per unit time. This is because link $w \to x$ could only forward one bit (a or b) to x, and thus y and z cannot simultaneously receive two bits, a and b, as indicated in Fig. 1(b). In Fig. 1(c), if the intermediate node w is allowed to code the two bits it receives from t and u respectively into one bit $a \oplus b$ (here, symbol $\oplus$ is Exclusive-OR operation) and to output $a \oplus b$ to x, sink y and sink z are able to obtain a, $a \oplus b$ and b, $a \oplus b$ respectively, which means two bits information is available at both y and z. Meanwhile, y and z can use a, $a \oplus b$ and b, $a \oplus b$ to get b and a by calculating $a \oplus (a \oplus b)$ and $b \oplus (a \oplus b)$ respectively.

1.1. Minimizing network coding resources

Currently, most of the network-coding-related research works suppose that coding operation should be implemented at all coding-possible intermediate nodes [3–5]. However, to achieve a desired throughput, coding operation may only be necessary at a subset of all coding-possible nodes [3–5]. In Fig. 2, there are two network coding schemes that could both achieve the maximum multicast throughput. Network coding scheme A adopts all coding-possible nodes, namely m and n, as shown in Fig. 2(a). Nevertheless, the same throughput is also obtained by network coding scheme B when only one of the two coding-possible nodes, m, is required to perform coding operation (see Fig. 2(b)). Since coding operation consumes computing time and increases date processing complexity, it is of great interest to minimize the amount of coding operation. Such problem is proven to be NP-Hard [3,4].

* Corresponding author. Tel./fax: +86 10 62282127.
E-mail address: jyf@bupt.edu.cn (Y. Ji).

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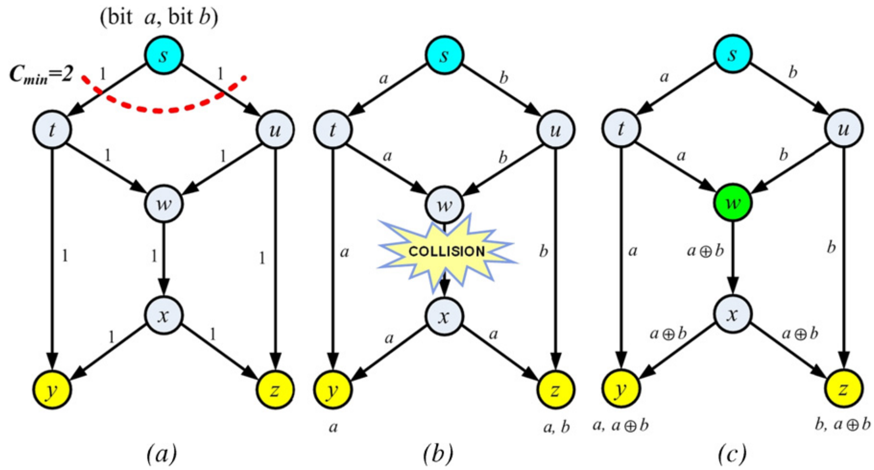

Fig. 1. Traditional routing vs. network coding: (a) a network topology with maximum multicast throughput of two bits per unit time; (b) traditional routing scheme, and (c) network coding scheme.

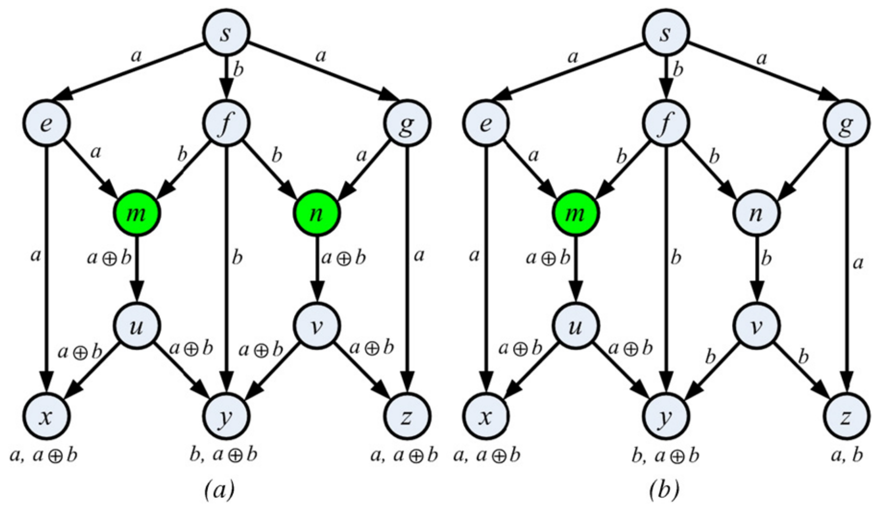

Fig. 2. Two different network coding schemes: (a) network coding scheme A with two coding nodes, and (b) network coding scheme B with only one coding node.

In order to solve this problem, several algorithms have been proposed, which are mainly based on either greedy algorithms or evolutionary algorithms [3–8]. In [6,7], greedy algorithms were used to minimize coding resource. However, both of the above algorithms assume that the nodes with multiple incoming links must carry out network coding. And their optimal efficiency depends on the selected sub-graph and the link traversal order. In [8], linear programming formulations were proposed to optimize various network coding resources. Nevertheless, the number of variables and the number of constraints both grow with the number of destination nodes. Thus, this method limits itself to the case where the number of sinks is not large. Some genetic algorithms (GAs) with both centralized and distributed versions were put forward to minimize the network coding resources where coding is required [3–5]. In addition, GA based algorithms seem to perform much better than minimal algorithms above. However, due to the inherent shortcomings of GA such as prematurity, slow convergence speed and weak global searching capability, poor optimization performance is usually led to.

1.2. Quantum-inspired evolutionary algorithm

Quantum-inspired evolutionary algorithm (QEA), a combination of quantum computation and genetic algorithm, has been widely studied [9–16]. Exploration and exploitation could be provided simultaneously, only if suitable evolution parameter values are selected. Having a great effect on optimization performance of QEA, the selection of suitable evolutionary parameters must be paid sufficient attention to. However, in most of the existing QEAs, the determination of evolutionary parameters does not take the differences among individuals into consideration. In [9–12], fixed rotation angle step (FRAS) schemes have been put forward. At arbitrary evolutionary generation, FRAS-based algorithm uses the same rotation angle step (RAS) strategy to evolve its population. If any two chromosomes are in the same case with respect to the corresponding lookup table, they will use the same RAS value to update. QEA with FRAS scheme often results in slow convergence since the RAS values in lookup table never change. Later, the dynamic rotation angle step (called DRAS below) schemes were proposed in [13,14], where new RAS values are provided adaptively at each generation. With DRAS schemes, the searching grid of QEA varies from large to small automatically, and it is of some help to accelerate the convergence and to achieve better optimal solutions. However, at any evolutionary generation, all individuals under DRAS schemes only refer to one lookup table to update, which means DRAS schemes are also designed for a population but may be not suitable for every individual.