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A nondominated sorting genetic algorithm for bi-objective network coding based multicast routing problems

Huanlai Xing *, Rong Qu

ASAP Group, School of Computer Science, University of Nottingham, United Kingdom

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ABSTRACT

Network coding is a new communication technique that generalizes routing, where, instead of simply forwarding the packets they receive, intermediate nodes are allowed to recombine (code) together some of the data packets received from different incoming links if necessary. By doing so, the maximum information flow in a network can always be achieved. However, performing coding operations (i.e. recombining data packets) incur computational overhead and delay of data processing at the corresponding nodes.

In this paper, we investigate the optimization of the network coding based multicast routing problem with respect to two widely considered objectives, i.e. the cost and the delay. In general, reducing cost can result into a cheaper multicast solution for network service providers, while decreasing delay improves the service quality for users. Hence we model the problem as a bi-objective optimization problem to minimize the total cost and the maximum transmission delay of a multicast. This bi-objective optimization problem has not been considered in the literature. We adapt the Elitist Nondominated Sorting Genetic Algorithm (NSGA-II) for the new problem by introducing two adjustments. As there are many infeasible solutions in the search space, the first adjustment is an initialization scheme to generate a population of feasible and diversified solutions. These initial solutions help to guide the search towards the Pareto-optimal front. In addition, the original NSGA-II is very likely to produce a number of solutions with identical objective values at each generation, which may seriously deteriorate the level of diversity and the optimization performance. The second adjustment is an individual delegate scheme where, among those solutions with identical objective values, only one of them is retained in the population while the others are deleted. Experimental results reveal that each adopted adjustment contributes to the adaptation of NSGA-II for the problem concerned. Moreover, the adjusted NSGA-II outperforms a number of state-of-the-art multiobjective evolutionary algorithms with respect to the quality of the obtained nondominated solutions in the conducted experiments.

1. Introduction

Multicast is a one-to-many communication technique that simultaneously delivers information from the source to a group of destinations (receivers) within the same network so that in a single transmission any receiver is able to obtain the original information sent from the source [38]. With the emergence of increasingly more multimedia applications such

* Corresponding author. Address: Room C79, School of Computer Science, University of Nottingham, Nottingham NG8 1BB, United Kingdom. Tel.: +44 0115 84 66594.

E-mail addresses: hxx@cs.nott.ac.uk (H. Xing), rxq@cs.nott.ac.uk (R. Qu).

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as video conferencing and IPTV, multicast has become one of the key supporting technologies in modern communication networks [4,17,18,44].

Network coding is a new technique that generalizes routing in communication networks [1]. Since its introduction in 2000, network coding has drawn a significant amount of research attention in information and coding theory, networking, cryptography, and so on. In traditional routing, each intermediate node (i.e. router) within a network simply forwards the data received from an incoming link to one or a number of outgoing links. However, in network coding based routing, any intermediate node can recombine (code) data received from different incoming links if necessary. Network coding has promising advantages in payload balancing [14,30,34], energy saving [7,45], security [5], robustness against failures [21], and so on. When incorporating network coding into multicast, the most attractive advantage is that (according to the MAX-FLOW MIN-CUT Theorem) the theoretical maximal throughput is always guaranteed [34].

Fig. 1 shows a comparison between network coding and traditional routing regarding the average data rate to receivers [46]. Fig. 1a is a network, where source *s* multicasts two-bit information (a) and (b) to node *y* and node *z*. Each link can forward a single bit at each time. According to the MAX-FLOW MIN-CUT Theorem, the theoretical maximal multicast throughput is two bits per time. However, as Fig. 1b illustrates, traditional routing can only obtain an average data rate of 1.5 bits per time unit due to the bottleneck link $w \to x$. As can be seen in Fig. 1c, if we allow node *w* to perform $a \oplus b$ ($\oplus$ stands for Exclusive-OR), both of the receivers obtain two-bit information at the same time, where original data can be decoded through $a \oplus (a \oplus b)$ and $b \oplus (a \oplus b)$. Hence, network coding can always achieve the theoretical maximal multicast throughput.

1.1. Related work

In network coding based multicast routing problems, the cost of a multicast session is usually considered as a minimization objective. Two types of costs, coding cost caused by coding operations and link cost caused by employing transmission links, have been considered, respectively. One stream of research investigates the minimization of the coding cost of a multicast session, i.e. how to minimize coding resources involved in a network coding based multicast session. In [15,32], two greedy algorithms have been proposed to reduce the number of coding nodes. Kim et al. present several centralized and distributed versions of genetic algorithm (GA) to find multicast sessions with the least amount of coding operations [24,25,28]. Ahn [2] and Luong et al. [37] propose two efficient evolutionary algorithms for coding cost minimization. Moreover, in our previous work, a number of estimation of distribution algorithms have been put forward to minimize the required network coding resources. These include quantum inspired evolutionary algorithm (QEA) [20,46], population based incremental learning (PBIL) [47,48] and compact genetic algorithm (cGA) [49]. The second stream of research aims to minimize the link cost of a network coding based multicast, assuming the cost only comes from flows occupying links. Assume each link (i, k) within the network is associated with non-negative values a_{ik} and c_{ik} which are the cost per unit flow and how much capacity is used by flows, respectively. The total link cost is thus denoted as $\Sigma a_{ik}c_{ik}$. In [10,35,36], the minimum-cost network coding based multicast routing problem is formulated as a linear programming problem and solved by a distributed algorithm. The third stream of research focuses on simultaneously minimizing two objectives, i.e. the coding cost and the link cost [26,27]. Experimental results show that there is not always a trade-off between the two objectives, e.g. in some instances, a single

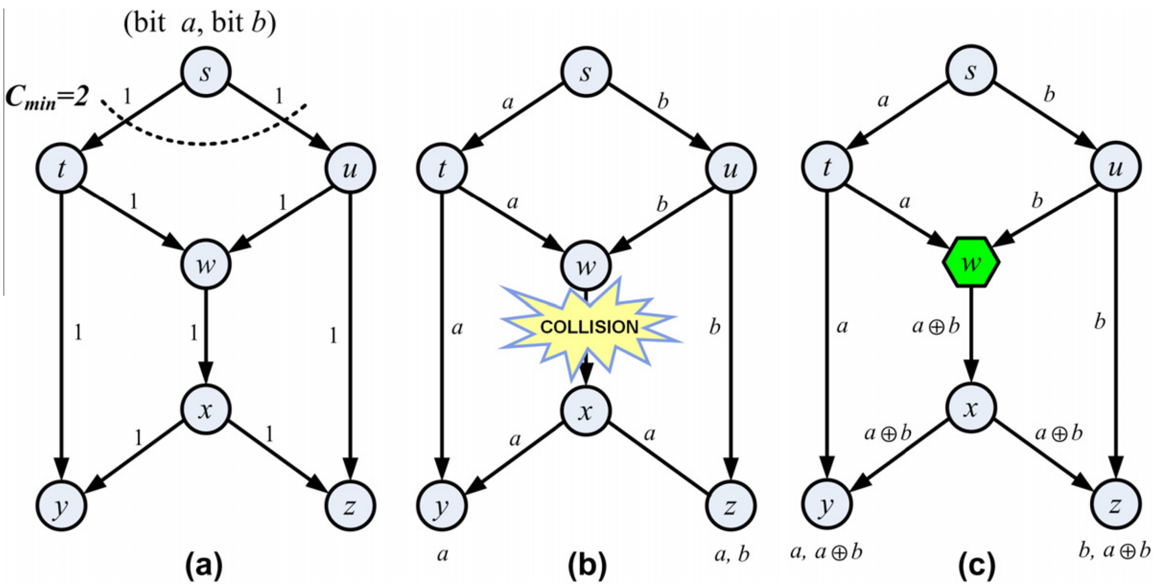

Fig. 1. Traditional routing vs. network coding [46]. (a) The example network. (b) Traditional routing. (c) Network coding.