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Meta-heuristic algorithms for optimized network flow wavelet-based image coding

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ABSTRACT

Optimal multipath selection to maximize the received multiple description coding (MDCs) in a lossy network model is proposed. Multiple description scalar quantization (MDSQ) has been applied to the wavelet coefficients of a color image to generate the MDCs which are combating transmission loss over lossy networks. In the networks, each received description raises the reconstruction quality of an MDC-coded signal (image, audio or video). In terms of maximizing the received descriptions, a greater number of optimal routings between source and destination must be obtained. The rainbow network flow (RNF) collaborated with effective meta-heuristic algorithms is a good approach to resolve it. Two meta-heuristic algorithms which are genetic algorithm (GA) and particle swarm optimization (PSO) have been utilized to solve the multi-objective optimization routing problem for finding optimal routings each of which is assigned as a distinct color by RNF to maximize the coded descriptions in a network model. By employing a local search based priority encoding method, each individual in GA and particle in PSO is represented as a potential solution. The proposed algorithms are compared with the multipath Dijkstra algorithm (MDA) for both finding optimal paths and providing reliable multimedia communication. The simulations run over various random network topologies and the results show that the PSO algorithm finds optimal routings effectively and maximizes the received MDCs with assistance of RNF, leading to reduce packet loss and increase throughput.

1. Introduction

The transmission of multimedia information over communication channels/paths has become a challenging problem with the increased usage of multimedia services in networks. Transmitting original source (information) naturally requires a significant amount of bandwidth and storage. This has been a strong motivation to examine and develop an efficient optimization method in order to use less bandwidth as well as finding the optimum network routings.

In multimedia transmission, original source image should be compressed for reducing redundancy in the image as well as efficient usage of bandwidth. There are two different approaches that have been applied to compress source image [1]. The first is lossless, where a compact representation of the source coding can be decoded to reconstruct the original signal without error. The second is lossy, which causes distortion in the original signal and the exact reconstruction of the original source cannot be achieved [1]. The purpose of using both techniques is to encode the source into a compressed digital representation that can be used for transmission. However, packet transmission problems such as packet dropping or congestion may occur over lossy transmission networks. For instance, there may be encounters with low capacity links, network congestion or excessive delay to deliver packets. To combat multimedia packet loss transmission problem, multiple description coding (MD coding or MDC) transmitting through multipath is preferred because even if one MDC packet is lost over a path, the lost MDC packet may be received via another path [1,2]. Thus, using this approach maximizes MDC packets over lossy networks since the probability of receiving packets at the destinations increases [3].

The descriptions which carry similar information of the original source can be efficiently generated by using various quantization techniques (e.g. multiple description scalar and vector quantization) [6,7] and sampling methods (orthogonal, quincunx) [8]. Since the quantization methods are used, transformation methods such as discrete wavelet transform (DWT) [3], discrete cosine transform (DCT) [4], and embedded zero tree wavelet transform (EZW) [5] provide significant improvements in terms of preserving the important information of the multimedia source. In this work, a wavelet-based multiple description scalar quantization method has been applied to generate the MDCs of the

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color images since such methods are known to provide excellent rate-distortion performance [3]. Thus, the important information or energy in the sub-bands of the transformed image will be protected. The generated MDCs with acceptable quality are transmitted over multipath in lossy networks but finding the optimal paths and providing enough bandwidth capacity from source to destination are the two complex problems because of the many potential intermediate destinations an MDC packet might traverse before reaching its final destination [9]. To find an optimum solution, various algorithms have been proposed to provide greater and efficient performance of communication. For instance, Jiazi et al. [38] proposed multipath Dijkstra algorithm (MDA) to obtain multipath and they show that the algorithm gains great flexibility by employing different link metrics and cost functions. Furthermore, genetic algorithms (GAs) and particle swarm optimization (PSO) are significant approaches to resolve the communication problems [10,11]. They are used for solving different NP-hard network problems such as K-shortest paths [12], constrained shortest-path [13], multi-objective shortest path [14] and network flow [15]. In the most of routing optimization problems, only one weight or cost associated with each network link has been considered to find the optimum solution, e.g. delay or length [10,11,16,17]. Begen et al. [18,44] examined multimedia transmission over optimized lossy networks. They state that each network link has more than one cost parameter such as packet loss rate, length and bandwidth as it makes the network routing optimization problem even harder. However, they neither provide an optimization method to solve the multi constrained network routing problem nor a path selection method. In this paper, a new multi-objective cost function and an enhanced path representation are explained to solve these open problems and the performances of meta-heuristic algorithms are examined to find optimal multipath in the multi constrained network problems.

The problem of simultaneously optimizing multiple weights and costs is defined as one of multi-objective network optimization. In the simulated network models, three different cost variables will be considered associated with each network link that will be used to optimize path length, bandwidth consumption and packet loss rate for receiving an acceptable quality of transmitted image. The strategies employed in [17] and [18] are used to select the numerical weights for each edge to optimize the shortest paths and packet loss rate. In this problem, the significant goal is to find optimal multi paths with minimum packet loss rate and path length as well as maximizing the average reconstruction quality of a received MDC-coded signal (image, audio or video) at the sink nodes. Meta-heuristic algorithms such as GA and PSO are employed in this work to provide an optimal trade-off between the cost values and the performances of them are compared with the MDA [38]. Three different fitness functions which are single objective shortest path, single objective minimal packet loss rate and multi-objective cost functions are employed for efficient result estimation in both finding optimal multipath and providing multimedia transmission. The simulations described in this paper consider undirected path graphs of a given node size n and edge size m. The optimization will employ a given set of MDC packet subsets and utilize the RNF algorithm, a GA and PSO. The main contribution and strength of the paper are as follows:

- A new multi-objective cost function is proposed and compared with the previously used single objective cost functions in terms of finding optimum multipath as well as increasing the probability of receiving multimedia packets at the destination nodes in lossy network problems [17,18].
- Two meta-heuristic algorithms which are GA and PSO algorithms have been adapted with both proposed multi-objective cost function and RNF algorithm, and they are compared with MDA [38].
- Average quality of received images is estimated in terms of optimized network resources and statistics based on three fitness functions.
- The effectiveness of the proposed multi-objective cost function has been shown in transmitting the multimedia information through the optimized network. Besides, creating descriptions using the wavelet based image coding has been further improved to produce MDCs of color image for the available bandwidth between the source and destination nodes.
- Priority encoding method is enhanced to reduce invalid paths for corresponding multi-cost problem in terms of reducing computational time for finding multipath in networks.

The rest of the paper is organized as follows: work related to MDC generation is given in Section 2, the model and analysis of the network problem is presented in Section 3, the details of meta-heuristic algorithms for solving the multi-objective network routing problem are explained in Section 4, results and discussions are provided in Section 5 and the paper is concluded in Section 6.

2. Work related to multiple description coding (MDC) generation

MDC provides a good quality of received images if losses are inevitable in the network and many works have been examined to design practical MDC systems. MD scalar quantization (MDSQ) is one of the most popular techniques which have been discussed in [6]. The improvement of MDSQ which is MD vector quantization is studied and reported in [7]. The quantization methods cause loss of the information of the original image. However, there are lossless MD image coding generation methods which are implemented by using source coding and transformation methods. The wavelet and discrete cosine transformation methods are most used techniques which have been widely discussed in the literature. For example, one of the most popular algorithms called set partitioning in hierarchical trees (SPIHT) used the wavelet approach [5]. Furthermore, Servetto et al. [3] applied the discrete wavelet transform (DWT) and resulting wavelet coefficients quantized by MDSQ to generate MDCs. Wang et al. [4] used the pairwise correlating transformation to generate multiple correlated descriptions in the framework of standard DCT-based image coding. Splitting an image into the descriptions was discussed by Zhang et al. [8].

This paper is focused upon two different problems, namely (i) optimizing network routings in order to get acceptable quality of received images in the lossy network and (ii) the simple generation of MDCs. Wavelets are attractive in image coding problems due to a tradition of excellent rate-distortion performance, so, we have applied MDSQ on a wavelet based colored image to generate MDCs.

2.1. Generating MDCs for proposed method

Even though the RGB color space can be used for pixel transmission, it has the disadvantage of illumination dependence. This means that there is a significant amount of correlation between the RGB components. If the illumination of an image changes because of packet losses in a lossy network, the achievement of high reconstructed images will be compromised.

Furthermore, the chrominance coefficients can be used for enhancement of the received image rather than modeling its intensity and can be neglected for larger changes without affecting our perception of the image. So it is necessary to transform the RGB color space to one of the color spaces where the separation between