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Scalable video transmission over multi-hop wireless networks with enhanced quality of experience using swarm intelligence ☆

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A R T I C L E I N F O

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A B S T R A C T

In this work, we take the advantages of the particle swarm optimization method which belongs to the family of swarm intelligence algorithms to find improved solutions for delivering digital video content with enhanced quality of experience to the end users over error-prone multi-hop wireless networks. In video transmission over such wireless networks, many network-based (packet loss, delay, etc.) and source-based (encoding quantization level, etc.) parameters can impair the perceived video quality. The main contributions of the proposed work are twofold. At first, an optimal bandwidth allocation framework is being developed based on the particle swarm optimization algorithm in which by incorporating an accurate video quality metric, the total weighted quality of experience of some competing video sources is being optimized. Secondly, these optimal rates have been used for differentiated quality of experience enforcement between multiple competing scalable video sources. The resulting optimal rates can be used as rate-feedbacks for on-line rate adaptation of a moderate scalable video encoder such as H.264/MPEG4 AVC. The aforementioned weight parameters are selected based on the importance of each video sequence's quality and can be associated with some previous service level agreement based prices. Some guidelines about the practical implementation of the proposed algorithm are given. Numerical analysis has been performed to validate the theoretical results and to verify the claims.

1. Introduction

Generally speaking, many difficult and non-linear engineering problems have found natural solutions which have been inspired from biological behaviors of the living kinds. Some important examples include neural networks, DNA computing, artificial immune systems and so on. Swarm intelligence (SI)-inspired optimization techniques are one of the most important tools for finding the optimal global solutions of many non-linear engineering problems. In these methods, the gradient of an optimization problem is unknown, perhaps because it cannot be defined due to a partially discontinuous fitness function, or because the fitness measure changes over time, or perhaps even because the fitness is undefined for certain regions of the search-space. One important sample of these gradient-free methods is the well-known particle swarm optimization (PSO) algorithm.

PSO is a multi-agent heuristic optimization method due to Kennedy and Eberhart [1]. The PSO method was originally intended for simulating the social behavior of a bird flock, but the algorithm was simplified and it was realized that the agents (here typically called particles) were actually performing black-box optimization. In PSO the population of particles is typically called a swarm. In the PSO method the particles are initially placed at random positions in the search-space, moving in randomly defined directions. The direction of a particle

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is then gradually changed so it will start to move in the direction of the best previous positions of itself and its peers, searching in their vicinity and potentially discovering even better positions [2,3].

Quality of experience (QoE) is an essential feature associated with successful video content delivery to the end-users. The main concern of most telecommunication operators about their video-based services is because of video service assurance. Competition between service providers is tight and the key to success is to provide a service with the highest possible level of user satisfaction (quality of experience level). Digital video data, which is stored in video databases and distributed through communication networks, is subject to various kinds of distortions during acquisition, compression, processing, transmission and reproduction. For example, lossy video compression techniques, which are almost always used to reduce the bandwidth needed to store or transmit video data, may degrade the quality, during the quantization process. For another instance, the digital video bit streams delivered over error-prone channels, such as wireless channels, may be received imperfectly due to the impairments occurred during transmission. Packet-switched communication networks, such as the Internet, can cause loss or severe delay of received data packets, depending on the network conditions or the quality of service parameters. All these transmission errors may result in distortions in the received video data. It is therefore imperative for a video delivery system to be able to realize and quantify the video quality degradations that occur in the system, so that it can maintain, react, control and enhance the quality of the video data. Effective image and video quality metrics are crucial for this purpose.

Recently some researchers such as Calyam et al. in [4], have proposed a suitable on-line metric for quality assessment of multimedia sequences. They have presented a novel framework that can provide acceptable on-line estimates of video QoE on network paths without end-user involvement and without requiring any reference video sequence. Their presented framework features the good, acceptable or poor (GAP) model, which is an approximately accurate model of QoE expressed as a function of measurable network parameters such as bandwidth, delay, jitter and loss. Using the GAP-model, their on-line framework can produce video QoE estimates in terms of good, acceptable or poor grades of perceptual quality solely from the on-line measured network conditions which is very close to the subjective mean opinion score (MOS) [5].

Scalable video coding (SVC) standardizes the encoding of a high-quality video bit stream that also contains one or more subset bit streams. A subset video bit stream is derived by dropping packets from the larger video to reduce the bandwidth required for the subset bit stream. The subset bit steam can represent a lower spatial resolution (smaller screen or spatial scalability), lower temporal resolution (lower frame rate or temporal scalability), or lower quality video signal (quality or SNR scalability). Hence, scalable video coding provides functionalities such as graceful degradation in lossy transmission environments as well as bit rate, format, and power adaptation [6]. H.264/MPEG-4 AVC is an example scalable codec which is developed jointly by ITU-T and ISO/IEC JTC 1. The desire for scalable video coding, which allows on-the-fly adaptation to certain application requirements such as display and processing capabilities of target devices, and varying transmission conditions, originates from the continuous evolution of receiving devices and the increasing usage of transmission systems that are characterized by a widely varying connection quality.

Multi-hop wireless networks are computer networks in which the communication links are wireless. In these networks, each node is willing to forward (or relay) data for other nodes and so the determination of which nodes forward data is made dynamically based on the network connectivity. Wireless networks can also form a network without the aid of any pre-established infrastructure in a self-organized manner [7,8].

The requirements of a specific set of quality of service (QoS) parameters (delay, jitter, packet loss, etc.) must be guaranteed for each real-time traffic transmitted over such wireless networks. However, for most real-time applications of wireless networks, intrinsic and possibly large levels of interference or collisions in the physical or link layers caused by radio transmission, media access protocols or time-varying topological changes provide challenging issues in guaranteeing these stringent QoS requirements.

Some of the routing protocols used in wireless networks introduce more than one feasible path for a source–destination pair. These category of routing algorithms are called multipath routing algorithms [9]. Multipath routing schemes can reduce interference, improve connectivity and allow distant nodes to communicate efficiently [9].

In [10,11] a congestion-minimized stream routing approach is adopted. In [11] the authors analyse the benefits of an optimal multipath routing strategy which seeks to minimize the congestion on the video streaming, in a bandwidth limited ad hoc wireless network. They also predict the performance in terms of rate and distortion, using a model which captures the impact of quantization and packet loss on the overall video quality. They showed that in such environments the optimal routing solutions which seek to minimize the congestion, are attractive as they make use of the resources efficiently. For low latency video streaming, they proposed to limit the number of routes to overcome the limitations of such solutions.

Some researchers such as Agarwal and Goldsmith [12], Adlakha et al. [13] and Zhu et al. [14] follow some congestion-aware and delay-constrained rate allocation strategies. Agarwal and Goldsmith in [12] introduce a mathematical constrained convex optimization framework by which they can jointly perform both rate allocation and routing in a delay-constrained wireless ad hoc environment. Adlakha et al. extend the conventional layered resource allocation approaches by introducing a novel cross-layer optimization strategy in order to more efficiently perform the resource allocation across the protocol stack and among multiple users. They showed that their proposed method can support simultaneous multiple delay-critical applications such as multi-user video streaming [13].