Computer Networks 97 (2016) 88–97

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Deadline-aware cooperative data exchange with network coding

Yang Sui [a], Xiumin Wang [a,*], Jin Wang [b], Lusheng Wang [a], Saihang Hou [a]

[a] School of Computer and Information, Hefei University of Technology, Hefei, China
[b] School of Computer Science and Technology, Soochow University, Suzhou, China

ARTICLE INFO

Article history:
Received 30 January 2015
Revised 26 November 2015
Accepted 8 January 2016
Available online 14 January 2016

Keywords:
Cooperative data exchange
Time critical application
Network coding

ABSTRACT

Recent work shows that Cooperative Data Exchange (CDE) with network coding can significantly improve wireless performance, especially in data exchange scenario. Moreover, wireless networks are now capable of supporting time critical applications, e.g., video streaming. Such time-critical applications usually impose a deadline on the packet reception, i.e., beyond which, the packet is useless or invalid to the users. In this paper, we propose a deadline-aware CDE scheme with network coding, so as to maximize the total number of packets that can be timely received/decoded at wireless clients/devices. We first formulate the problem into an integer programming, and prove that it is NP-hard. For the case when the deadline of the packets is the same, we theoretically analyze the performance of two specific schemes. We then design an efficient heuristic algorithm to solve the general problem, which is based on an auxiliary graph model. Finally, simulation results demonstrate the effectiveness of the proposed scheme.

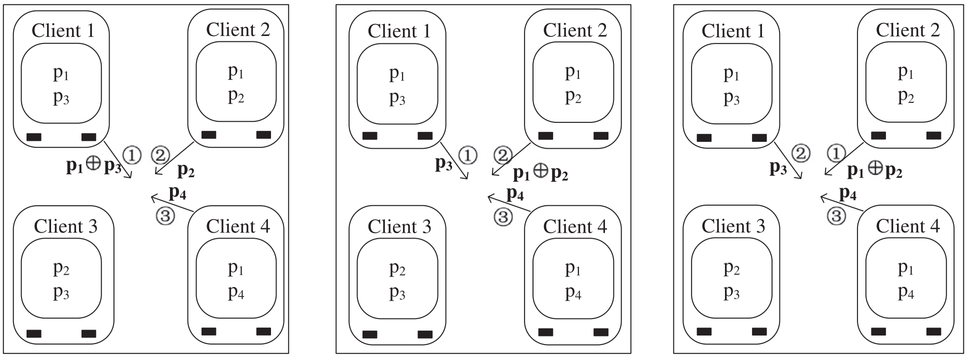
1. Introduction

In recent years, a growing demand on large file downloads and video applications at handheld wireless devices/clients has put an increasing burden on wireless communications. Because of the heavy load of the servers, it is impractical for wireless clients to download all the files from the servers. Inspired by the success of peer-to-peer (P2P) content delivery systems, one solution to address this issue is to allow wireless clients to cooperatively exchange the data among themselves, named *Cooperative Data Exchange* (CDE). Since introduced in [1], the CDE problem has attracted great attention in the research community. In CDE, each wireless client initially holds a subset of packets, and collectively they hold all the packets. Instead of downloading the packets from the server, CDE allows wireless devices to exchange the data among themselves over a lossless common broadcast channel [1–3], so as to make sure each client finally gets the complete packets. Compared with the tradition scheme, e.g., server-based transmission, CDE has two advantages. Firstly, the short-range communication among wireless clients is often more reliable and faster. Secondly, the bandwidth reserved at the server can serve more clients in the system.

Network coding [4–6], a cross-layer technology, has received extensive research attention in wireless community, due to its significant benefits in improving wireless throughput, reliability etc [7,8]. Recent studies show that network coding also improves the performance of CDE problem. With network coding, the client can linearly encode the packets in their buffers over a finite field, before sending the packets out. Specifically, the objectives studied in the literatures on CDE problem include: minimizing the total number of transmissions required for CDE problem [1–3,9], minimizing the total transmission cost/delay

* Corresponding author. Tel.: +86 055162901537.
E-mail addresses: yangsui@mail.hfut.edu.cn (Y. Sui), wxiumin@hfut.edu.cn (X. Wang), wjin1985@suda.edu.cn (J. Wang), wanglusheng@hfut.edu.cn (L. Wang), saihanghou@gmail.com (S. Hou).

http://dx.doi.org/10.1016/j.comnet.2016.01.003
1389-1286/



(a) The first scheme (b) The second scheme (c) The third scheme

Fig. 1. An example where the deadlines of the packets p_1, p_2, p_3, p_4 are 1, 1, 2, 3, respectively.

of CDE problem [10–16], or solving some security or error correction issues in CDE problem [17,18], etc.

With the increase in both wireless bandwidth and the computational capability of wireless clients, wireless networks are now capable of supporting time critical applications, e.g., video streaming. Such time-critical applications usually require that the packet must be received in a timely fashion, i.e., a deadline is imposed on the packet reception, beyond which the reception becomes useless (or invalid) [21–23]. For example, in wireless location-based services, the queried information (e.g., the traffic jam) is valid only within a local area, and when the mobile user (e.g., the vehicle) leaves the area, the information becomes useless [23]. In the literatures, several works have studied time critical applications. However, they all assume that there exists a source node (or sender) having the complete packets in the system. Instead, in CDE problem, each node only holds a subset of packets, and thus the sender varies during packet transmissions. Hence, the scenario of CDE problem brings new challenge to satisfy the Quality of Service (QoS) for time critical applications.

In the literatures, there are lots of works on delay minimization problem for CDE [13–15]. Specifically, the work in [13] minimizes the total transmission delay of the packets, by adaptively selecting the transmission rate at the client. In [14,15], authors propose a relay-based CDE scheme to minimize the total transmission delay, with the aid of a relay node. The above literatures work well in optimizing the overall delay of the packet receptions in CDE problem. However, none of them considers the packet reception deadline of any specific packet, which is especially important for time critical applications. Most related work to our problem is in [16], which uses instantly decodable network coding (IDNC) [19,20] in CDE problem. With IDNC, the coded packets can be instantly decoded at the clients, which thus significantly reduces the minimum mean decoding delay of the packets. However, [16] omits the facts that the packet in time critical applications must be received before a deadline, and different packets may be imposed with different deadlines. To avoid the expiration of the packet reception, the packets with emergent deadlines should be satisfied/decoded first at the clients. Hence, designing a deadline-aware CDE scheme, which will be studied in this paper, is quite important to improve the QoS of time critical applications.

We now use an example in Fig. 1 to illustrate our problem, where there are four packets p_1, p_2, p_3, p_4 to be disseminated to four wireless clients c_1, c_2, c_3, c_4 in the system. Initially, the subset of packets held by four clients c_1, c_2, c_3, c_4 are $\{p_1, p_3\}$, $\{p_1, p_2\}$, $\{p_2, p_3\}$, $\{p_1, p_4\}$, respectively. That is, the packets required by c_1, c_2, c_3, c_4 are $\{p_2, p_4\}$, $\{p_3, p_4\}$, $\{p_1, p_4\}$, $\{p_2, p_3\}$, respectively. Similar to [1,2], we assume that the client can hear the packets sent from any other client. As shown in Fig. 1, without considering the deadline of the packet receptions, all the three transmission schemes can guarantee that each client can finally decode/get all the packets. For example, in Fig. 1(a), after receiving packets $p_1 \oplus p_3$ (from client 1) and p_2 (from client 2), client 4 can get its "wanted" packets, e.g., decoding p_3 from $(p_1 \oplus p_3) \oplus p_1$.

However, for time critical applications, a deadline may be imposed on the packet reception. Assume that the deadlines of the packets p_1, p_2, p_3, p_4 are 1, 1, 2, 3 respectively, and each transmission consumes a single time slot. Then, we check the three schemes given in Fig. 1. As shown in Fig. 1(a) (which first let c_1 send $p_1 \oplus p_3$, and then let c_2, c_4 send packets p_2 and p_4, respectively), packet p_2 will miss its deadline at clients c_1 and c_4. In other words, two packets cannot be satisfied timely. Alternatively, if we use the scheme in Fig. 1(b) (which first let c_1 send p_3, and then let c_2, c_3 send packets $p_1 \oplus p_2$ and p_4, respectively), p_1 will miss its deadline at c_3, and p_2 will miss its deadline at both c_1 and c_4. Compared with the first scheme, the scheme in Fig. 1(b) satisfies less requests. However, as shown in Fig. 1(c), if we change the transmission order of the packets $p_1 \oplus p_2$ and p_3 in Fig. 1(b), we can see that all the packets can be successfully decoded before the deadlines. Compared with the above three schemes, the third scheme achieves the best performance, in terms of satisfying the deadlines of the packet receptions at wireless clients.

In this paper, we consider time critical applications in CDE problem. Compared with previous works on CDE, which mainly focus on how to select the sender and encode the packet, our work also needs to determine the sequence of the transmissions. By considering the deadline of the packets, the objective of this work is to maximize