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An adaptive disorder-avoidance cooperative downloading method

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ABSTRACT

Applications of heterogeneous wireless networks can help to achieve ubiquitous services. Cooperative downloading is a download technique used on cellular networks and wireless self-organized networks. It helps wireless users who are nearing the limits of their data plan to download data from the Internet. However, the existing studies on cooperative downloading techniques omit the problem of data disorder. Data disorder can decrease the quality of services experienced by users and increase memory usage. In this paper, we model cooperative downloading using queue theory and propose a calculation method for solving data disorder and decreasing download time. Based on the calculation method, an adaptive disorder-avoidance cooperative downloading method is proposed. The method consists of two parts: an adaptive task dissemination algorithm and a dynamic task delay prediction mechanism. The algorithm is implemented based on the calculation method that takes into account the dynamic features of wireless networks. We also propose a prediction model based on neural network learning and moving average, then use the model in the prediction mechanism to enhance the performance of the proposed method in scenarios with dynamic download rates. We used Network Simulation version 2 for the simulation, and simulation results show that the proposed method can solve the data disorder problem and be adapted to mobile scenarios. Furthermore, it can decrease the download time.

1. Introduction

With the development of wireless communication techniques, heterogeneity has become a prominent characteristic of modern computing environments [1,2]. Cooperative downloading is a downloading technique that operates over both long-range communication networks (cellular networks) and short-range communication networks (self-organized networks) [3]. Under cooperative downloading, a user (primary user) can ask other users (cooperative users) to download data using their data plan allowances to help him/her. The primary user decomposes the task of downloading a file into small tasks (e.g., downloading a segment of the target file). Cooperative users download segments using their data plan allowances and forward the segments to the primary user via short-range communication links. The benefits of the cooperation are two-sided. On one hand, the primary user can still access the Internet even if he/she has already run out of data plan; on the other hand, cooperative users can obtain rewards from cooperation and can manage their data plan more efficiently [4]. However, cooperative users will probably have selected different Internet service providers (ISPs), such as China Mobile or China Unicom, and bought different services, such as 2G, 3G, and 4G. All these differences can cause various task delay and the problem of data disorder. For instance, the head of the target file may be downloaded after the tail, which delays the time when content can be used and impacts the primary user's service experience, especially if the file can be used while downloading (such as streaming media) or there are priorities among segments. The disorder problem can be described as a case when the completion order of a task is different from its index. We call this difference the *C-I difference*. Let C_i be the completion order of Task i, then the *C-I difference* of Task i is $|C_i - i|$, and the average *C-I difference* is $1/M \sum_{i=1}^{M} |C_i - i|$, where M is the number of tasks. Our aim is to design a disorder-avoidance method that can decrease the average *C-I difference* as much as possible without any extra communication overhead or increase in download time.

We propose a cooperative downloading method for solving the data disorder problem in this paper. The proposed method consists of two parts: an adaptive task dissemination algorithm and a dynamic task delay prediction mechanism. The main contributions of our work are as follows:

- We model the downloading process using queue theory and propose a calculation method for minimizing the average *C-I*

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difference in theory. Furthermore, considering the dynamic features of wireless networks, we derive a recursive version of the calculation method and propose the adaptive task dissemination algorithm. In each step of the recursion, the result is calculated according to the parameters in real time. The simulation results show that the maximum usage delay (MUD) caused by disorder can be decreased by 85% under the mobile scenarios by applying our method.

- A task delay prediction mechanism is proposed for enhancing the adaptive capacity of the proposed method under dynamic download rate scenarios. We use the moving average model to implement the prediction model and improve it based on the basic idea of neural network learning. Hence, the prediction results are more accurate. The dataset of [5] was used to test the performance of our model, and the test results show that the average prediction error is less than 3%.
- By taking into consideration the time of task completion for users, we only assign tasks to users with sufficient download rates to avoid the "long tail" of the overall download process. The simulation results show that our method can make full use of available download links and cut off the long tail caused by cooperative users with low download rates.

The rest of this paper is organized as follows. Section 2 briefly browses related work on the cooperative downloading techniques. The system model of the cooperative downloading that we focus on is introduced in Section 3. We present the calculation method in Section 4. The details of the adaptive cooperative downloading method are presented in Section 5. Section 6 presents the results of the simulation. We conclude our work and state some future work directions in Section 7.

2. Related work

There have been many studies on cooperative downloading techniques. Most focus on popular content distribution (PCD), in which all users are interested in the same file. The traditional approaches are broadcasting and probabilistic replication [6]. Combining probabilistic replication with the basic idea of BitTorrent, a successful protocol for downloading popular content in wired networks, [7] proposed SPAWN, which is a swarming protocol consisting of a gossip mechanism and a piece-selection strategy. Furthermore, to get rid of piece selection, network coding has been introduced into cooperative content distribution systems [8–10]. The problem of finding the optimal number of transmissions for RLNC(Random Linear Network Coding)-based cooperative content distribution systems was then categorized as the "coded cooperative data exchange problem" by [11], and it has been studied extensively by [12–14]. There are also some studies discussing how to encourage cooperation under this scenario [15–17], such as the instance pay-off method in [18], fair cooperative content-sharing service proposed by [3], and fair cost allocation method proposed in [19]. The above work was all aimed at PCD. In contrast, we focus on general content downloading scenarios, in which a user may download any file from the Internet, which is not necessarily the same as the others.

Additionally, some studies have investigated content downloading in an environment where devices carried by vehicles move too fast to connect well with Roadside Units (RSUs). This occurs because the commonly used communication techniques for smart transportation systems such as Dedicated Short Range Communication [20] are short range. Trullols-Cruces et al. [21] and Liang et al. [22] assumed that a network consisting of vehicles is delay-tolerate, and they used the help of passing vehicles to forward the traffic of vehicles to a destination RSU. Zhou et al. [23] modelled the driving habits of vehicles on the highway and proposed a linear cluster formation scheme (ChainCluster) for selecting appropriate vehicles as helpers. Furthermore, Sardari et al. [24] considered the limited cooperation-buffer of the helpers and used rateless coding at the RSU side to achieve reliable dissemination from an RSU to the vehicles. A survey on this area can be found in [25]. In contrast to the above work, we focus on cooperation consisting of long-range communication (device-to-cellular access point) and short-range communication (device-to-device).

Cooperation that consists of long-range communication and short-range communication can lead to significant performance gains because short-range wireless technologies provide higher data rates given of their geographical proximity [26]. For general content downloading in this scenario, Do et al. [27] considered the mobility of users and proposed PatchPeer, which selects the user (Closest Peer) with the shortest Euclidean distance from the primary user as the cooperative user, so that the local network with short-range communication can be more reliable. Shijie et al. [28] proposed a Cooperative Content Fetching-based strategy (CCF). CCF consists of a stability estimation model (SEM) and a communication quality forecast model (CQFM). Using SEM and CQFM, CCF selects the stable user with the highest bandwidth as the cooperative user. The above approaches can make the local network more stable, but simply using the user with the best condition as the cooperative user cannot make full use of download links. Tuo et al. [4] proposed a data plan sharing system to help smart phone users manage their data plan more efficiently. Using a dynamic task dissemination strategy, the download links are all fully used in the system, and download time is decreased. However, the disorder problem is not considered.

Disorder can delay the time when content can be used and decrease the memory utilization, especially for files that can be used while downloading. Memory is a limited resource, especially for mobile devices. If the disorder problem is solved, the segments of the target file can be used as soon as they are downloaded, and then they can be removed if the operating systems require it. The advantages are not only good utilization of memory, but also good service experience. Therefore, it is very important to solve the disorder problem. There have been some studies addressing the data disorder problem [29–31]. However, all of them aim at solving the package disorder of multipath routing or traffic splitting (a survey can be found in [32]). Multipath routing or traffic splitting is very different from cooperative downloading. Under multipath routing, a client makes multiple connections directly with a server [33,34]. There is a continuous flow on each connection. Cooperative downloading does not have these direct connections, or a special "server side" like multipath routing, which makes its package disorder solutions hard to apply. Therefore, it is very important to develop new methods for solving the disorder problem of cooperative downloading systems.

3. System model of cooperative downloading

In the cooperative downloading system, users can be classified into two types:

- Primary User (PU): a user who needs to download a file from the Internet, but cannot finish it by him/herself because he/she does not have a sufficient data plan.
- Cooperative User (CU): a user who helps a primary user to download parts of the target file from the Internet and gets rewards from the primary user.

The system model of cooperative downloading is presented in Fig. 1. The primary user broadcasts requests to his/her direct neighbours, and the neighbours accepting the request become cooperative users. We assume that the mobile devices are carried by