Energy Adaptive Mechanism for P2P File Sharing Protocols

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Abstract. Peer to peer (P2P) file sharing applications have gained considerable popularity and are quite bandwidth and energy intensive. With the increased usage of P2P applications on mobile devices, its battery life has become of significant concern. In this paper, we propose a novel mechanism for energy adaptation in P2P file sharing protocols to significantly enhance the possibility of a client completing the file download before exhausting its battery. The underlying idea is to group mobile clients based on their energy budget and impose restrictions on bandwidth usage and hence on energy consumption. This allows us to provide favoured treatment to low energy devices, while still ensuring long-term fairness through a credit based mechanism and preventing free riding. Furthermore, we show how the proposed mechanism can be implemented in a popular P2P file sharing application, the BitTorrent protocol and analyze it through a comprehensive set of simulations.

Keywords: P2P file sharing application, Energy Adaptive Computing, BitTorrent, Energy groups

1 Introduction

As mobile devices become more and more indispensable part of our daily lives, the popular desktop applications, such as the peer to peer (P2P) file sharing applications, will continue to migrate to such devices. However, P2P file sharing applications are typically bandwidth and energy intensive and can be a significant drain on the mobile battery.

In this paper, we propose a novel mechanism for adapting the bandwidth usage of P2P file sharing applications based on the energy constraints of the devices for higher energy efficiency [1]. Specifically, we provide differentiated service to clients based on their energy budget. The battery constrained clients define an energy budget for downloading the file which enables them to adapt their contributions to the network and the service they receive from the network based on it. The protocol ensures the provisioning and delivery of the desired service rate to the clients based on their energy budget. To prove the feasibility of the proposed mechanism, we discuss the implementation of the proposed mechanism in the context of BitTorrent protocol, a popular P2P file sharing protocol.

The paper is organized as follows. In Section 2 we discuss related works. Section 3 introduces the proposed mechanism and we discuss the related challenges and solutions in the implementation of the proposed mechanism in Section 4. In Section 5, we briefly discuss the implementation of our proposed mechanism in the context of BitTorrent protocol and analyze it through simulation. Section 6 concludes the paper with directions for future work.

2 Related Works

Several solutions have been proposed in the literature to improve the energy efficiency of the P2P file sharing protocols. Middleware based solution as discussed in [2–4], where the task of downloading the file is delegated to a proxy [2, 4] or cloud [5] for higher energy efficiency. The end device only wakes up to receive the file from the proxy or cloud when it has been downloaded. Thus by transferring the computational and protocol overheads to an external device, the mobile devices conserve energy. Different mechanisms for deployment of proxy-based solutions are described in [3]. In [5], a cloud based solution is presented, wherein the BitTorrent client is running remotely in the cloud and is controlled through a thin interface on the mobile device. Though the middleware based approaches guarantee that the file is downloaded irrespective of the battery constraints of the mobile devices, they must exist in a trusted or a controlled environment for security and privacy. Furthermore, the availability of middleware may be local to a network and may not be ubiquitously available. In [6], the task of connection management and query processing of the P2P protocol is delegated to a low cost external hardware based proxy to conserve energy. However, this approach requires the use of additional hardware, which is not desired. In [7], a green BitTorrent protocol is proposed, which introduces a sleep state in the TCP protocol to minimize transmissions. To prevent snubbing of sleeping peers, the authors presented an architecture as well as a mechanism to distinguish between sleeping and dead peers.

Unlike the discussed approaches, we address the problem of adapting the bandwidth usage of the P2P file sharing clients based on their energy budget for higher energy efficiency. We define such approaches under the ambit of Energy Adaptive Computing (EAC) [1]. Since the proposed mechanism requires modifications only to the application protocol, it can be used in conjunction with any traditional energy conservation techniques. To the best of our knowledge, no previous approaches in the literature aim at empowering the P2P file sharing applications with EAC.

3 Energy Adaptive Mechanism for P2P File Sharing Applications

The proposed mechanism exploits the following two characteristic of the mobile devices to adapt their energy consumption based on their energy budgets. 1) Mobile device consumes more energy when transmitting than receiving. Essentially, during transmission, the signal is amplified to achieve the desired signal to noise ratio for successful decoding at the receiver. Thus attributing for the higher energy consumption. 2) It is much more energy efficient for the mobile device to download the file faster, i.e. at high download rate. After each transmission or reception, mobile devices continue to remain in active state for a short duration, called tail time, in anticipation of another packet. Frequent occurrence of tail time can result in significant energy consumption for the mobile devices [8]. At high download rates, packets are either received in the tail time or in large single bursts, thus, preventing the frequent occurrence of tail time and reducing the average energy per transfer [8]. In the following sections we discuss the network scenario and show how the above mentioned energy consumption characteristics are exploited in the proposed mechanism.

3.1 Network Scenario

In this paper, we consider a content sharing network, wherein the content is shared and distributed among users using a partially decentralized P2P file sharing protocol. Each content can either be free or paid, wherein paid content are purchased using credits. Credits can be purchased or gained through participation in the network, as explained in Section 3.2. For accounting and credit management, each user is assigned a unique id, using which it must authenticate itself before joining the network. We refer each user in the network as peer.

In partially decentralized P2P file sharing applications, a super node or central server monitors and maintains information about the peers and the network. Peers prior to joining the network must communicate with it, to be able to identify the neighboring peers. We define neighboring peers of a peer P, as those which are downloading the same file as P. Each file being downloaded is divided into smaller pieces of fixed size. Peers exchange or download pieces of mutual interest from each other. After a peer has received all the pieces of the file, it combines them to reconstruct the whole file. On completion of download, a peer may then choose to stay back in the network and keep providing pieces of file to other peers as a "seed".

The network is assumed to be composed of both battery constrained peers, like smartphones and tablets, and non battery constrained peers, like desktops. Each battery constrained peer defines an energy budget for downloading the file prior to joining the network. Energy budget of a battery constrained peer is the maximum amount of energy it wants to consume for downloading the file. It is determined while taking into consideration the available energy of the device, the energy consumption and bandwidth usage profile of other applications running on it and the maximum bandwidth the device can allocate to the application for downloading the file.

3.2 Description of the Proposed Mechanism

In the proposed mechanism, peers are divided into two groups, namely Energy Sufficient (ES) group and Energy Constrained (EC) group. Peers in ES group are characterized as either those who are not battery constrained or battery constrained peers who can successfully download the file within their specified energy budget. Peers in ES group download the file only from neighboring peers in the same group as themselves. No restrictions are imposed on the bandwidth usage of peers in ES group. A battery constrained peer, on joining the network can determine whether it will be able to download the file successfully within its given energy budget based on the average upload and download rate of the peers in the ES group. If not, it becomes part of the EC group. The energy consumption of the battery constrained peer for a given bandwidth usage profile can be determined using the Stochastic KiBaM model [9]. The model is fast and reliable with a maximum error of 2.65%, hence, is suitable for real-time applications. Thus peers in EC groups are characterized as comprising of battery constrained peers who cannot download the file within their specified energy budget.

To facilitate peers in EC group to download the file within their energy budget, we divide the peers into smaller energy groups. This subdivision enables us to group peers with similar energy budget together and provide differentiated service to them based on it. The differentiated service allows the peers to adapt their bandwidth usage and download the file. Each energy group is characterized as having a unique energy consumption profile depending on the maximum upload and download rate to which peers in that group must adhere to while downloading the file. Specifically, we exploit the fact that it is much more energy efficient for the mobile devices to operate at high download and upload rates. Thus groups with high permissible upload and download rate can be characterized as having low energy consumption. The energy consumption in the group increases as the maximum permissible upload and download rate of the group decreases. To download a file within its energy budget, peers join an energy group with lower energy consumption profile than its energy budget.

Moreover, we impose the following restrictions on the communication pattern of peers. Peers in an energy group can only download the file from neighboring peers in the same group as themselves, using the traditional P2P file sharing protocol. We assume peers in each energy group upload at the maximum permissible upload rate of the group. In P2P file sharing protocol, peers prefer to associate with neighboring peers having same or higher upload rates than them. Since the P2P file sharing application works on the principle of mutual exchange, the restrictions on communication pattern of the peers allows them to discover neighboring peers with similar upload rates, thus, allowing the network to converge to a stable state faster [10].

In P2P file sharing application, the download rate the peer gets is proportional to the its upload rate. Since no peer will upload more data to a neighboring peer than what it has downloaded from it, we can say the average degree of proportionality is 1, assuming the contributions from seeds are insignificant when compared with those of neighboring peers. Thus the average download rate the peer gets in an energy group is equivalent to the maximum upload rate of the group. The peer can also get additional download rates from seeds. However, the download rate of the peer may still be not sufficient for it to download the file within its specified energy budget. Hence, we allow the peers in energy groups to receive additional download rates from neighboring peers in ES group. We assume the peers in ES have some residual energy or are not battery constrained, and hence, can provide additional download rates to neighboring peers in energy groups in exchange of credits.

The use of credits for purchasing additional download rates from neighboring peers in ES group has the following advantages. 1) It prevents free riding. 2) In traditional P2P file sharing applications, a peer must contribute to the neighboring peers in ES group to increase its download rate. The use of credits allows peers to gain additional download rate at low energy cost as more energy is consumed when transmitting than receiving. 3) It provides long-term fairness. Peers can accumulate credits when downloading a file by providing additional download rates to neighboring peers in other groups. The credits can be used by battery constrained peers in future to enhance their download rate and lower their energy consumption when they join the network to download a file with low energy budget. Furthermore, both non battery-constrained and battery-constrained peers, can use the gained credits to purchase content in the network. The rate of exchange of credits and bandwidth is kept high for low energy group and it decreases from low to high energy. Low energy group peers are given more preference when allocating additional download rates as they are operating at low and strict energy budgets. Such a variable exchange rate promotes fairness as it compensates for the favourable treatment. Furthermore, it dissuades peers from joining energy group with high download rates (low energy groups) owing to their higher exchange rate. Figure 1 shows the interactions between peers in three energy groups, namely low, medium and high, and ES group, based on the proposed mechanism.

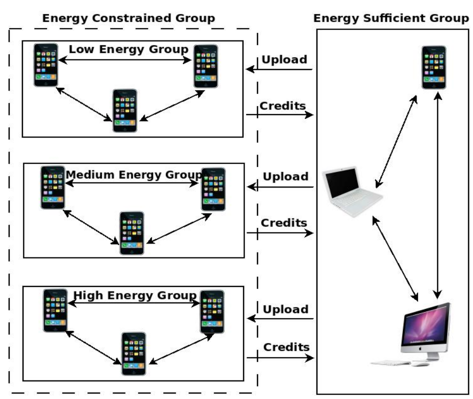

Fig. 1: Interaction between peers in and across groups

4 Challenges and Solutions in Implementation of the Proposed Mechanism

We discuss some of the challenges in the implementation of the proposed mechanism and propose solutions to them. The proposed mechanism requires us to address the following challenges; 1) design and creation of energy groups; and 2) allocation of the additional download rates to peers in energy groups based on demands.

4.1 Design and Creation of Energy Groups

Let E be the set of energy groups, where $|E| = M$. For each energy group $E_i \in E$, let U_{E_i} and D_{E_i} be the maximum upload and download rate of the group. The set of energy groups E are ordered by the maximum upload rate of each group in descending order, i.e. $U_{E_1} > U_{E_2} > \ldots > U_{E_M}$. Since a peer can get additional download rates from seeds as well as purchase from neighboring peers in the ES group, the maximum download rate it can receive in an energy group is kept higher than the maximum upload rate of that group, i.e. $D_{E_i} > U_{E_i}$. To keep the energy consumption profile of each group unique, the maximum download rate of each group of each group is kept as $D_{E_1} > D_{E_2} > \ldots D_{E_M}$. The minimum energy with which a peer can download a file in an energy group is given as when the peer is performing at the maximum upload and download rate of the group. Since, $(U_{E_1} + D_{E_1}) > (U_{E_2} + D_{E_2}) > \ldots > (U_{E_M} + D_{E_M})$, the minimum energy consumption in the energy groups can be given as $E_1 < E_2 < \ldots < E_M$. Thus group E_1 has the minimum energy consumption and requires peers to dedicate the highest amount of bandwidth for downloading the file. The minimum energy consumption of the groups increases as we decrease the maximum permissible upload rate of the peers in the group.

However, we must first be able to restrict the upload and download rates of peers in P2P file sharing applications to be able to create energy groups. Hence we carried out a survey of mobile P2P file sharing applications to determine its feasibility. It was revealed that mobile applications, like Transmission P2P App for Nokia N900 and MobileMule, of some popular P2P file sharing protocols, like BitTorrent [11] and eMule [12] respectively, allow us to specify restrictions on the maximum upload and download rate that can be used by them. Thus establishing the feasibility of limiting the bandwidth usage of peers for creation of energy groups.

4.2 Distribution of Additional Download Rate to Peers

On joining ES group, each peer announces the amount of additional upload rate it wishes to offer. Similarly, on joining an energy group each peer announces the amount of additional download rate it wishes to purchase from neighboring peers in ES group. The central server must provide peers in ES group wishing to offer additional download rates with a set of neighboring peers in energy groups who wish to purchase it and inform how to distribute it among them. The total additional download rate (V_{E_i}) being requested by peers in energy group E_i is given as $V_{E_i} = w_{E_i} \cdot min(R_{E_i}, BW_{E_i})$. Where R_{E_i} is the total download rate the peers in group E_i wish to purchase and w_i is the weight assigned to group E_i, such that $w_{E_1} > w_{E_2} > \ldots > w_{E_M}$. This ensures that the peers with low energy budget get higher preference when allocating additional download rates to them. BW_{E_i} is the total average download rate required by peers in group E_i to make their download rate equal to maximum download rate D_{E_i} of the group, as given in Equation 1.

$$BW_{E_i} = \begin{cases} 0 & \text{if } D_{E_i} \leq \bar{\delta}_{E_i} \\ (D_{E_i} - \bar{\delta}_{E_i}).\bar{x}_{E_i} & \text{if } D_{E_i} > \bar{\delta}_{E_i} \end{cases} \tag{1}$$

In Equation 1, $\bar{x}_{E_i}$ represents the average number of peers in group E_i and δ_{E_i} is the average download rate of the peers in group E_i. Thus V_{E_i} gives the total weighted download rate that peers in energy group E_i can purchase or want to purchase. The total additional download rate being offered by a peer in ES group is distributed among the energy groups in the ratio of their demands, i.e. $(\frac{V_{E_1}}{\sum_{E_i \in E} V_{E_i}}, \frac{V_{E_2}}{\sum_{E_i \in E} V_{E_i}} \dots \frac{V_{E_M}}{\sum_{E_i \in E} V_{E_i}})$. The total additional download rate allocated to energy group E_i is distributed among the peers in that group in the ratio of their individual demands.

5 Implementation and Simulation of the Proposed Mechanism

To evaluate the proposed mechanism, we first discuss its implementation it in the context of the BitTorrent protocol [11], a popular partially decentralized P2P file sharing application, and analyze its performance using simulation.

5.1 The BitTorrent Protocol

The BitTorrent [11] protocol employs a centralized tracker mechanism for peer discovery. A peer, say P, intending to download a file, say F, first downloads the ".torrent" file containing information about the tracker and file F from the host web-server. The tracker maintains a list of peers currently downloading the file F. Upon contacting the tracker, peer P receives a list of neighboring peers that it may contact for exchanging chunks of the file F. The peer P individually contacts the neighboring peers and requests them to exchange chunks of file with itself. On mutual consent, the peers exchange chunks of the file F of mutual interest.

The tracker, in the BitTorrent protocol, assumes the function of central server. The tracker maintains the group membership information of each peer and their choice of action, i.e. whether they wants to provide additional download rate or purchase additional download rate, along with their identity. Each peer is provided with two sets of neighboring peers. The first set consists of neighboring peers in the same energy group as themselves from which they can download the file using the BitTorrent protocol. For peers in energy groups, the second set contains neighboring peers in ES from which it can purchase additional download rates. For peer in ES group, the second set contains neighboring peers in energy groups to which it should provide additional download rates. The tracker runs the allocation algorithm for allocating additional download rates and informs the peers in ES group how to distribute it among the neighboring peers in the second set.

5.2 Simulation and Results

Furthermore, we carried out simulations to evaluate the performance of the proposed mechanism. Simulations were conducted in ns2 [13] using a BitTorrent module [14] modified for our purpose. We assumed 3 energy groups in EC group, $E = \{low, medium, high\}$ exist, representing peers with low, medium and high energy budget respectively. The maximum upload rate of low, medium and high energy group was considered as 64, 128 and 192 *kbps* respectively and the maximum download rate as 128, 192 and 256 *kbps* respectively. The upload rate of the peers in ES group was considered as 256 kbps. We considered a file size of 700 MB. Based on analysis of traces from live BitTorrent P2P network [15], the peer arrival rate for each energy group was kept as 0.0045 $peers/sec$. We assume a peer on completion of download becomes a seed with probability 0.5. All peers in a group operate at the maximum upload rate of the group as well as the additional download rate peers in a group wish to purchase is equal to the rate required to make their download rate equal to the maximum download rate of the group. The weights assigned to each group was kept as $w_1 : w_2 : w_3 = 3 : 2 : 1$ and the simulation time was kept constant as 4.5 hrs. Each data point represents the average value computed over 10 iterations of each simulation. In the

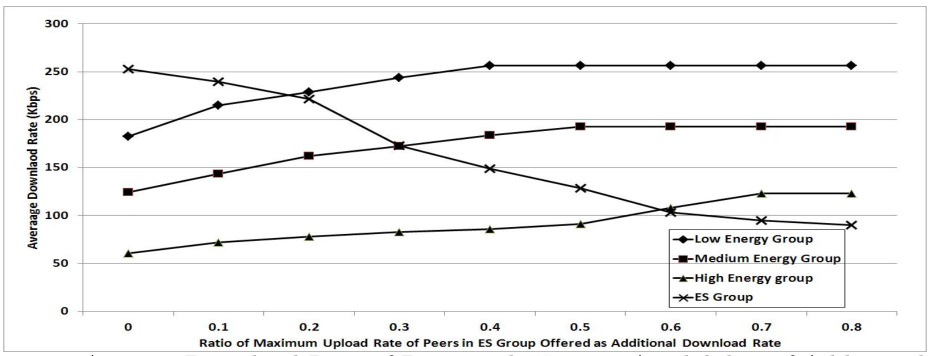

Fig. 2: Average Download Rate of Peers with Varying Availability of Additional Download Rate

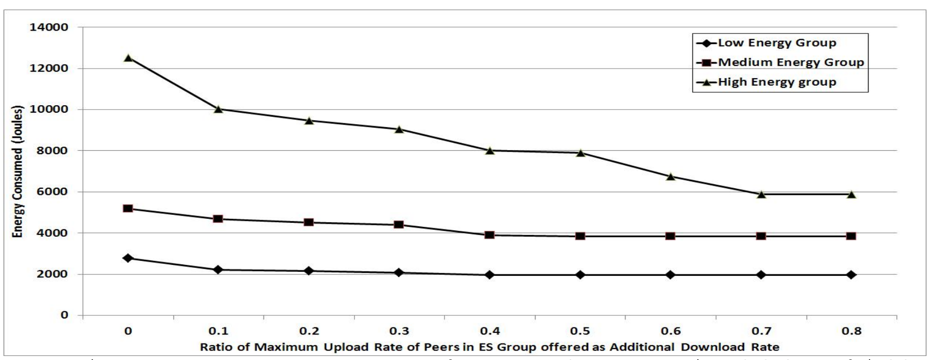

Fig. 3: Average Energy consumption of Peers with Varying Availability of Additional Download Rate

first experiment, we observed the average download rate of peers in each group with varying availability of additional download rate from neighboring peers in ES group, as shown in Figure 2. The additional download rate offered by peers in ES group was varied as the ratio of their maximum upload rate. The allocation algorithm gives higher preference to low energy group as peers in the group achieve maximum download rate faster. The rate at which peers in an energy group approach the maximum download rate of the group is dependent on the weights assigned to each group. When peers in low energy group achieve the maximum download rate of 256 kbps, the peers in medium and high energy group are allocated the remaining additional download rate in the ratio of their demands. Hence, the rate at which peers in medium and high energy group approach the maximum download rate increases. As the peers in the ES group provide more additional download rate, they reduce their contributions to neighboring peers in their group. Since, BitTorrent works on tit for tat principle, peers in ES group receive proportional download rates from neighboring peers in their group and become increasingly more reliable on the the download rate being provided by the seeds, thus, their download rate reduces. Furthermore, using the application traces collected in the first experiment, we generated traffic to (from) Google Nexus One smartphone and measured the energy consumption for downloading the file, as shown in Figure 3. The results establish our claim that peers in low energy groups are able to download the file using less energy than peers in high energy group. The energy consumption increases from medium to high energy group. Thus establishing the feasibility of using energy groups having unique energy consumption profiles to download the file within the specified energy budgets of peers.

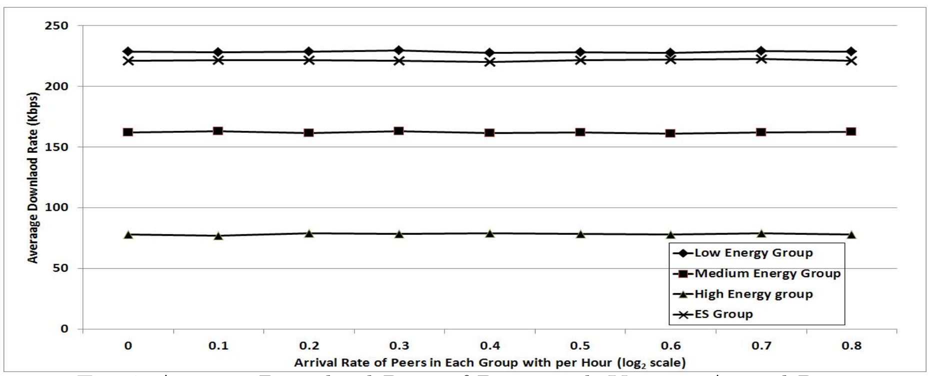

Fig. 4: Average Download Rate of Peers with Varying Arrival Rate

In the second experiment, we carried out a study of the effect of arrival rate of peers on the average download rate of each energy group, as shown in figure 4. We kept the fraction of maximum upload rate peers in ES group offer as additional download rate constant at 0.5. The download rate a peer gets in a BitTorrent system is independent of the peer arrival rate [10]. Since, the implementation of the proposed mechanism does not require changes to the inherent characteristics of the BitTorrent protocol but only requires us to put constraints on their bandwidth usage, we inherit the properties of the BitTorrent protocol. The BitTorrent protocol along with the additional upload rate allocation model ensures that the system remains robust to the varying peer arrival rates.

6 Conclusions

In this paper, we have proposed a framework that effectively allows low energy clients to "borrow" energy from clients with sufficient energy, and thereby increase their probability of downloading the file. We provided a detailed description of challenges and associated solution in the implementation of the proposed framework in the context of BitTorrent protocol. Through an exhaustive set of simulations we analyzed the proposed framework and showed how it can provide differentiated service to low energy clients. Having shown the feasibility and effectiveness of the proposed mechanism, we intend to extend it to other popular P2P file sharing applications, like eMule and BitTorrent DHT protocol, and carry out real-world experiments. Finally, we wish to examine the new security issues in BitTorrent protocol brought in by the credit based mechanism and the proposed energy adaptation capability as well as provide a optimal energy group selection algorithm for battery constrained peers.

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